

been collected to build a crib to weight down the mattress, and, as soon as I was fully advised of the situation, I gave directions to build a crib only three feet high, the whole length of this mattress, to fill this crib with boulders, earth, or anything that could be obtained, to ramp the up-stream side, so that it would not afford a hold for the ice to catch on, and to cover this ramp with a slope of earth which should be wetted as it was made and thoroughly frozen. Although the winter was exceedingly cold, there was comparatively little wind, and a good two months' work was done before the 8th of March, when the rising water drove the men off the work and flooded the dike.

From this time forward nothing could be done, the water continuing unusually high through the whole month of March (see Plate 4). On March 27th, the first signs of moving ice were observed. On the 28th, it moved entirely across the river, but not any great distance. On the 29th, it continued moving at intervals; and on the 30th, came the grand rush from above, the water rising, as already stated, to 164.4, and flooding the whole country. The flood was so high that the discharge of ice passed entirely over the dike-work, doing it scarcely any damage. A short piece of the upper edge of the mat, near the center of the work, was turned over on to the crib, and the whole of one end seemed to be undermined, but practically no harm was done. On the 4th of April, the gorge above Fort Abraham Lincoln broke, and the water fell so as to expose the dike-work.

Although little harm had been done by the break-up, the situation was as perplexing as ever; the main channel was still between the dike and the west shore. The water gradually cut away about 200 feet at the west end of the mattress, where the crib had not been thoroughly filled with stone, but the opening between the dike and the west shore did not pass the whole discharge of the river, and the inclination of the dike seemed to have the desired effect, in causing the flow of water on the east side gradually to increase, at the expense of the discharge through the western opening. On the 8th of April, slush ice began to run east of the mattress, and on the 18th, the east channel had become the better channel of the two, so that the transfer steamer began to use it. The river was now working in the way that we desired, but the open channel on the west side was a source of very grave apprehension.

A short spur made of sand bags was built near the lower end of the dike to check the action of an eddy, and, on the 4th and 5th of May, two clusters of piles were driven at the east end of the dike, which should serve as mooring piles, to handle barges of riprap from. Early in May, it seemed

to me expedient to make an attempt to close the west channel by driving a pile bridge across it. I felt that the chances were very much against being able to do this before the June flood, but I determined to make the attempt, though not expecting to succeed. The driving of these piles was begun on the 10th of May, but on the 22d one of the bents washed out, and on the following day another; a week later, five more bents were carried out, and on the 11th of June nearly all the pile-work had been destroyed. The piles, however, proved enough of an obstruction to help settle the main channel on the east side, but their operation in this way was but slight, and the failure which had been anticipated was realized.

As the dike-work was very low, the average elevation not being more than 162.4, a wall of sand bags was built on top of the crib-work, about three feet high, which was expected to increase the deposit of the summer flood. This wall was finished on the 28th of May, and it seemed to have the desired effect, though the bags themselves were almost entirely destroyed. Riprap stone was delivered on the east shore, below the bridge line, where it was loaded on barges, which were towed up to the clusters of mooring piles at the end of the dike, and there unloaded. The first barge-load was taken there on the 27th of May; on the 17th of June, 1,000 tons of riprap had been unloaded, and on the 25th of July, 2,025 tons. By means of this riprap, the dike was held through the summer flood against the most rapid current in the river, which scoured out the bottom to a depth of 50 feet, and whirled around the end of the dike with the violence characteristic of the Missouri in flood time. For three months the water off the end of the dike was 50 feet deep.

On the 25th of July, the high water having receded enough to make it safe to begin work again in the west channel, the driving of a pile bridge was resumed. Early on the morning of the 3d of August, before daylight, there came up a shower, which deluged the whole country, accompanied by hail, which broke every window on the north or west side of every house in Bismarck, and in this storm the pile-driver boat was wrecked; after a few days' delay, however, the boat was raised and pile-driving resumed. On the 25th of August, this pile bridge was completed, and the first load of riprap stone was run out on the dike by this route; this continued to be the method of receiving riprap for the dike until the completion of the work. A transfer landing was built on the sand-bar below the bridge line, and tracks laid from the dike track to this landing, thus making a short crossing for the transfer boat, which was used till the river closed in November.

The opening west of the dike had been somewhat enlarged during the

summer flood, and the pile bridge was about 900 feet long. The low water season was now at hand, and arrangements had been made to close the opening entirely by willow mattress work, but it soon became evident that the silting action of the water passing through the west channel was too valuable to be lost, and I decided to do nothing towards closing this channel until winter, expecting that during the fall a sand-bar would be formed over nearly its entire width; in this respect I was not disappointed.

On the night preceding Monday, November 14th, a gorge of slush ice formed, which caused the river to fall about three feet, and stopped the running of the transfer. The construction of a temporary pile bridge across the main channel, to serve as a winter bridge, was begun at once. On the 17th of November the river finally closed for the winter, and on Saturday, the 19th, the first train crossed on this temporary bridge. The river was very low, and the bridge only 600 feet long. This bridge, which was built in five days, was kept in constant use for 132 days, being finally abandoned on the 30th of March, 1882.

During the winter the pile bridge at the west end of the dike was filled with earth from the borrow pit in the bluff near Mandan, from which the material for the embankment of the west approach was taken. The first train-load was dumped December 7th, 1881, and the whole bridge had been filled on February 3d, 1882. In March the stringers were taken out, and the track ballasted with scoria from the Bad Lands.

The west channel was now entirely closed, and the river at length confined to the opening where the bridge was being built, but matters were not yet entirely satisfactory; instead of crossing to the east shore, about half a mile above the bridge, as had been expected, the channel continued to keep near the west shore, striking the end of the dike violently, and then passing down stream between Piers II and III. A sand-bar had formed, which reached from the eastern shore to the west side of Pier II, so that the whole length of what is now the main channel span was over dry land. This sand-bar was of no small assistance in the construction of Pier II, and would have been of great assistance in the erection of the superstructure, if the contractors had not been so far behindhand that they were unable to take advantage of it; but it showed that the rectification works had not yet done their full work.

The level of the track on the dike was about 163.1. On the 5th of April, when the ice broke up, the river rose to 163.267; and the ice swept over the bank and carried off the track. The track was restored and the embankment repaired; a transfer landing was also built near the situation

of the one used in the preceding fall, and kept in use until it was washed out on the 13th of June.

For some reason, which it was very difficult to explain, the channel seemed still to follow the west shore, and, instead of crossing above the bridge, it struck the dike about 500 feet from its easterly end, where the current, turning to the east, ran parallel to the dike, and swept around the end of the dike with quite as much violence as in the preceding year; the stone, however, with which the end of the dike had been covered, was enough to make it secure, and, through two entire seasons, the dike stood with a channel 50 feet deep immediately off the end of it, and, in the second season, with no perceptible settlement of the surface; a better proof of the permanency of our work could hardly be desired. At a point, however, 500 feet from the end, where the current first struck the dike, the work was less stable; the current undermined the upper edge of the mattress foundation, which settled down, and was followed by the crib; the crib, however, had sufficient strength in itself to hold up for some time after the foundation mat had settled, when it would settle suddenly for a considerable length. The first settlement took place on the 17th of June, and caused a break in the dike 60 feet long, this break being located about 280 feet from the end of the dike; the water poured through this opening and scoured a hole over 20 feet deep immediately below it, but soon spread out and began depositing, so that the effect of the break was to raise the general level of the sand-bar and really do more good than harm. A second settlement took place on the 19th of June, and a third on the 27th. A new opening occurred on the 1st of July, and further settlements on the 17th, 18th, and 21st of July, by which time the dike had settled for a total length of 335 feet. The settlements seemed to be quite uniform in character, generally about 8 feet deep, and never to occur twice in the same place; they were generally accompanied by a raising of the lower ends of the crib logs, showing that the wash was entirely on the up-stream side of the dike, the crib rocking on a midway point. A track was laid across the settlement, on stringers supported by blocking and small cribs, and communication restored across the dike track, so that a transfer landing below the bridge line on the west side was again put in use on the 5th of August. Riprap stone, brought down on cars, was then thrown in, and the settled portion of the dike restored to its original level entirely with stone, since which time it has seemed to be as permanent as could be desired.

As an additional precaution to provide against a current parallel with the dike, a spur was built late in 1882, running up stream, from a point

about 200 feet from the end of the dike, and terminating in a round mattress 150 feet in diameter. The position of this spur is shown on one of the maps on Plate 2. This work was not finished till the winter of 1882-3, and though it settled during the spring so as to be entirely out of sight, it seemed to have had the desired effect.

It was not till the spring of 1883 that the channel finally assumed the position which was desired, crossing gradually from the old upper landing, on the west side, two miles above the bridge line, to strike the east bluff about 500 yards above the bridge line, and then follow down the east shore, so that the main, navigable channel lies between Piers I and II, and follows the east shore in front of the old warehouse below the bridge line. The channel seems now to have taken the position which it was originally designed to force it into, and though local disturbances may occasionally throw it over to Pier III, it is believed that it will generally be where it should be, along the east shore. To provide against injury from the channel in this position, the eastern shore was trimmed to a true slope, on a 30' curve (11,460 feet radius), for 900 feet above the bridge; a track was laid along the edge of the slope at an elevation of 1645, and the slope riprapped with field boulders. In the future, the place which may require the most attention will be the shore on the west side, above the old transfer landing, where the river is now cutting into the bottom land towards Mandan; this cutting, however, can continue for several years without injury, as the effect of the river's cutting as much as half a mile into the bottom land would only be to make a bend towards the west, which would throw the current back towards the east bluff below, in the direction which it is desirable it should follow.

In the construction of the dike there have been used 32,754 tons of riprap stone, about 1,750 cords of brush, 20,100 cubic yards of earth, besides the logs in the crib-work and the piles and other materials in the bridges across the west channel, and the stringers used temporarily for the track. The riprap is composed almost entirely of granite boulders, which were collected from the prairies on the west side of the river, the specifications requiring that none of these stones should weigh less than 50 pounds, and at least one-half of the whole amount should consist of stones weighing more than 500 pounds. It is perhaps fair to state that the actual cost of completing the work, from the time it was placed in my hands, in January, 1881, with the channel west of the work already done, has been greater than it would have been to do the entire work from the beginning, with the river in the condition it was when it was examined in the spring of 1880.

V

SUBSTRUCTURE

The contract for the substructure was let, as already stated, on January 28th, 1881, to the firm of Saulpaugh & Company, this firm consisting of Thomas Saulpaugh, George W. Saulpaugh and John Crubaugh. As Bismarck was situated in an unsettled country, being at that time 150 miles beyond any settled agricultural country, and more than 400 miles from the nearest labor market, it was thought important to keep the control of the labor on the work in as few hands as possible, and so to place the whole substructure, including foundations, in the hands of a single contractor. The desired result was only partially attained. The contractors were men of great experience in masonry and coffer-dam foundations, but had never done any pneumatic work; they therefore made an arrangement with the firm of Rust & Coolidge, of Chicago, to build and sink the caissons for Piers II and III. There was no fault to find with the manner in which these sub-contractors carried out their part of the work, but, as the event proved, in the matter of labor, there was no advantage gained in letting the substructure contract to a single party. The specifications for the substructure are given in Appendix B. Besides the four principal piers described in these specifications, the substructure included a small abutment, which supports the east end of the east approach span, and a pair of Cushing cylinders, which support the iron bent which carries the west end of the west approach span; the little east abutment was built by Saulpaugh & Co., under a special arrangement, and the Cushing cylinders were put in by day's work. The abutment at the east end contains 70 yards of masonry, and has a foundation of concrete; it is built of granite, with undressed beds, a small portion which is visible above the ground having an ashlar face. This little abutment and the Cushing cylinders are both shown on Plate 9.

At the time the substructure specifications were drawn and the contract let, it was supposed that the hard material which had been found by the borings was a soft species of rock; further borings proved that this was not the case; it was a hard stratified clay, which, in the matter of strength and behavior under strain, resembled a rock more than earth; being almost impervious to water, it seemed to be entirely indestructible under water; when exposed to the air however this very hard clay rapidly slacked, and after a few days could be picked to pieces, and, when once reduced to a powder, it could be mixed into a soft puddle, like any other clay; so long

as it remained in position under water, it was a thoroughly good foundation, better than some of the softer varieties of rock, though of course not equal to a first-class, hard stone. This clay extends indefinitely over this whole portion of Dakota; occasionally, thin layers of sandstone not much harder than the clay, and veins of lignite are found in it, but neither the sandstone nor the lignite is sufficiently extensive to make an important feature in the great mass of clay. Near the site of Pier I, a hole was sunk into this clay 100 feet deep, which stood without tubing; at the site of Pier II, a hole was sunk about 30 feet into this clay, which, 26 feet below the surface of the clay, passed through a thin layer of sandstone; this layer being at some places within the area of the foundation less than 6 inches thick. At a point in the city of Bismarck about a mile and a half from the east end of the bridge, an attempt was made to sink an artesian well, and a hole was drilled 1,300 feet, without finding water; the elevation of the surface at this place was 1760; occasionally, very thin streaks of what appeared like a soft rock were struck in drilling this well, but practically the entire hole was run down through clay, the bottom of which had not been reached when the boring was abandoned. Experiments were made to determine the tensile strength of this clay, and the compressive strength of small cubes unsupported at the sides, and also the bearing strength of surfaces in position; the experiments in tension were made on briquettes cut from solid pieces of clay, and similar in shape to those used in testing cement; the experiments in compression were made on 1-inch cubes, also cut from solid pieces of clay; the samples were kept under water, after they were brought from the foundations, so as to avoid air slacking. The results of these experiments are given in Appendix C. A large number of borings were made to ascertain the position of this clay, besides those which were made in 1880, before I took charge of the work. A full list of all these borings is given in Appendix D; they are all referred to the axis of the bridge, and are described as north or south of such a station, Station 0 being 75 feet east of the center of Pier I, and the points being described as north or south of the points on the bridge line, these directions not being a true north and south, but being taken at right angles to the axis of the bridge.

The first actual work done at the bridge site was on the 12th of May, 1881, when ground was broken for the foundation of the east abutment; little was done at that time, however, and the concrete foundation and masonry of this little abutment were not put in till the following July. The lower parts of the Cushing cylinders on the west side were put in in Decem-

ber, 1881, and January, 1882, but the top sections were not put in till the following May.

PIER I

Pier I was located on the east side of the river close to the edge of the river bank, the ground here being at an elevation of about 1640; ground was broken for this foundation on the 13th of May, 1881, but the excavation was discontinued shortly thereafter till the 15th of July, when it was resumed actively. An open pit was excavated and carried down to the elevation 1600, or more than 20 feet lower than the surface of the river along-side, without the use of a pump. The surface earth was soft, but very soon the hard clay was reached; this clay had an irregular surface, and the stratifications followed the contours of the surface; a few feet below the surface, several large sandstone boulders were found embedded in the clay; these boulders had no horizontal strata, but seemed to be built up by a series of layers conforming in shape to the outer form of the boulders. The material seemed entirely impervious to water; it was never necessary to pump, and the only water which came in was a very strongly alkaline spring water, which evidently did not come from the river, and which was kept out without difficulty by baling. A derrick was set up along-side, and the material was hoisted out; when enough water had come into the pit to be inconvenient, a tub-load of water was lifted out.

The foundation pit was made 50 feet long and 24 feet wide. On the 15th of August, it had been carried down to an elevation of 1612.5; although the material was entirely firm, it showed a tendency to slack off on the surface and slide down, with an irregular vertical cleavage, and it had been found expedient to put in waling timbers and sheeting, and to brace across the pit. At this depth (1612.5) the pit was divided into three sections, and the south section was carried down to the final depth first. The excavation was suspended from the 20th to the 30th of August, and on the 6th of September, the southern section had been carried to its full depth; on the same day the concrete filling of this section was begun, and completed on the 13th. The north section was next excavated; it was begun on the 14th of September, finished on the 18th, and the concrete filling was finished on the 21st. The center section was then excavated between the two masses of concrete; this excavation was completed on the 22d, and had been filled with concrete on the 25th. The pit was now for its whole size filled with concrete from the bottom (elevation 1600) to an elevation of about 1612. Four feet more of concrete were then put in over the full size of

the pit, bringing the concrete filling to the elevation 1616. Two thicknesses of 12 by 12 inch timber were then laid on the surface of this concrete, enclosing a space 20 feet wide and 47 feet long, which was then filled with concrete, bringing the surface of the concrete foundation to 1618. The concrete filling was entirely finished on the 1st of October, 1881.

The masonry was begun on this surface of concrete, the first stone being set October 4th. On the 30th of November, the pier was finished.

The concrete used for this pier was composed of Portland cement and sand, generally in the proportions of three of sand to one of cement, which was mixed in a machine consisting of a shaft with a spiral, similar to conveyor shafts used in grain elevators, with teeth set between the flights of the spiral, and running in a horizontal wrought iron trough; while not so perfect as some of the more expensive mixers, it did excellent service. The concrete mixed by this machine was wheeled to the pit and dumped in; at the same time, a lot of rubble-stone, consisting generally of small granite field boulders, weighing about 50 pounds, or less, were thrown by hand into the mass of mortar, the throwing in of the stone and the dumping of the mortar being carried on simultaneously. The result was a thoroughly compact mass, which seemed to contain no voids whatever, about one-third of which was stone. It is believed that for large masses, a much more perfect concrete can be made in this way than in the usual method of mixing broken stone with sand and cement before putting it in place.

There are in this foundation 779.3 cubic yards of concrete, and there were used in it 1,275 barrels of Portland cement, being at the rate of 1,636 barrels per cubic yard.

The estimated weight and pressure upon the foundation of this pier is as follows:

779.3 cubic yards concrete, at 3,510 lbs.	-	2,735,343 lbs.
952.1 cubic yards masonry, at 4,330 lbs.	-	4,122,593 "
257 lineal feet of superstructure and moving load, at 5,000 lbs.	-	1,285,000 "
Total,	-	8,142,936 lbs.
Deduct 779.3 cubic yards of water, at 1,687 lbs.	-	1,314,679 "
Leaving as net weight on the foundation,		6,828,257 lbs.
Area of base, 1,200 sq. feet.		
Average pressure per sq. foot, 5,690 lbs.		
" " " inch,	39.5 "	

Of course the actual weight on the foundation is the gross weight (8,142,936 lbs.) plus the atmospheric pressure, but in determining the actual labor of the foundation—that is, the increase in pressure caused by the construction of the pier—the weight of the water displaced should be deducted. As the water never falls to the extreme low water mark, excepting temporarily, when the river first closes with ice, at which time the water is never very deep, and the pier receives a great deal of support from the lateral friction of the sand around it, the low water stage for this calculation has been taken at 1618, instead of the assumed extreme low water, 1616. As the pier is situated back from the shore line, and the foundation is 40 feet below the natural surface of the clay, it would be correct to make a further deduction, corresponding to the weight of the clay excavated. The foundation and masonry of Pier I are shown on Plate 5.

PNEUMATIC WORK

Piers II and III are both founded on pneumatic caissons; these caissons are of the same size and similar in construction. The details of the construction of these caissons are shown on Plate 11. They are built of pine timber, sheathed on the outside with two thicknesses of 3-inch oak plank, the working chamber being lined with one thickness of 3-inch pine plank calked to render it air-tight. These caissons measure, outside of the planking, 74 feet long by 26 feet wide and 17 feet high; the walls of the working chamber are inclined at an angle of 45°, thus making a V-shaped space between the inner and outer walls of the caisson, and the space above the roof of the working chamber is formed of an open crib-work of pine timber. The timbers are bolted through at all points of intersection, and the side walls are well drift bolted besides. The V-shaped spaces between the two walls, and the spaces in the crib-work above the roof of the working chamber, were filled with Portland cement concrete, which was generally made of sand and cement in the proportions of two parts of sand to one of cement, rubble-stone being worked into the upper portion of this filling in the same manner as at Pier I. The cutting edge of the caisson was made of wrought iron.

The pneumatic machinery was mounted on a barge 100 feet long, 26 feet wide and 5 feet 4 inches deep; this barge is shown on Plate 15. The machinery consisted of two No. 4 Clayton air compressors, each with two air cylinders 14 by 15 inches, and two steam cylinders 14 by 15 inches, and a No. 12 long stroke Cameron pump (old No. 8), to drive the Eads sand pumps. Steam was furnished by two 60-horse power boilers, which did the

work satisfactorily, but had no power to spare, though one of them was ample to drive the air-pumps when the Cameron was not in use. The same boat contained a room for the use of the pressure men.

The air-lock used was a double lock, designed specially for this work. It consisted of two chambers seven feet high, each of which was in plan a half circle 6 feet in diameter, separated by two spaces 3 feet square; one of these intermediate spaces connected with the shaft leading into the working chamber, and the other with the shaft leading to the top of the masonry, the two semicircular chambers forming really two independent air-locks. The air-lock was placed on top of the caisson and buried in the masonry, the shell being left there when the work was completed, the doors and all the fittings being removed. It proved exceedingly convenient, especially when it was necessary to take out clay through the lock. When once put in position, it was fixed for the whole work; it was completely out of the way, and was so situated that it was safe from any injury, either from the swinging of stone in laying masonry or from any accident that might occur in the caisson. The only objection to this form of air-lock is that the shell of the lock is necessarily lost, but the value of this shell is more than made up for by the increased convenience which it gives in the execution of the work. This air-lock is shown in detail on Plate 14.

Each caisson was fitted with two supply shafts to pass the concrete filling through, the details of which, and their connections, are shown on Plate 14. The air supply was received through a 4-inch pipe, and the water supply through a 5-inch pipe. Two Eads sand pumps were used to excavate the sand, the discharge of each of which was carried off through a 4-inch pipe; these pumps were connected with the same water supply pipe, and were never used at the same time.

In the prosecution of the work, it was found that the weight of the caisson and masonry was not sufficient to sink the caisson without relieving the air pressure; rapid blowing off was never resorted to, but the pressure was relieved to a sufficient extent to allow settlements, the men remaining in the caisson all the time; these settlements were usually about two feet, and were accomplished in about five minutes.

PIER II

The caisson for Pier II was built on the east bank of the river, about a thousand feet below the bridge line; this caisson contains 133 M. B. M. of timber including the oak plank, 58,500 pounds of wrought iron in bolts and rods, 10,320 pounds of cast iron in washers, and 12,900 pounds of wrought

iron in the cutting edge. The erection of this caisson was begun on the 16th of June, 1881; it was built broadside to the river, fitted with a false bottom to float it, and launching ways were built supported by piles; the caisson was completed and ready for launching about the end of July.

On the 30th of July, a cluster of anchor piles was driven above the site of the pier, and also some piles to which the caisson was to be moored immediately adjoining its position; no other false works were provided for.

On the 2d of August, arrangements were completed for the launch of the caisson; about half an hour before the time set for the launch, the caisson was observed to be straining its lashings, and one of the sub-foremen, without considering the situation, ordered the lines cut at once and the caisson let go; the result was that it started towards the river before the ways were clear, the shoes struck the obstructions and were thrown sideways off the ways, and the caisson stopped. One end of the caisson had moved farther than the other, and it was necessary to straighten it around and jack it up, so as to replace the shoes, before it could be launched; it was not considered expedient to attempt to jack it back to its original position at the upper ends of the ways.

Four days were lost by this unfortunate accident, and on the 6th of August, the caisson was finally launched. As it did not have a run of the full length of the ways, it did not acquire sufficient momentum to carry it entirely clear of the ways when it struck the water, so that the side next to the river settled into the water, while the shore side was still supported by the ways; it was necessary to set some timbers against the side of the caisson and push it off with jacks, an operation which consumed several hours' time, but did no particular harm, and in the afternoon the caisson floated, in good condition.

During these unfortunate delays, a sand-bar had formed opposite where the caisson was launched, with only about three feet of water over it, and this sand-bar extended up stream beyond the site of Pier II. The caisson drew about five and a half feet, and it was out of the question to take it across the bar to the site of the pier. To facilitate towing, it was fitted with a false prow, and on the 9th of August, it was dropped down to the transfer landing, about a quarter of a mile below where it was launched.

The 9th of August was a quiet, still day, the weather being admirably fitted for handling a heavy tow like the caisson. The caisson was placed in front of the bow of the transfer boat, and held straight by bridle lines on each side; the transfer boat then moved out into the stream and attempted to push the caisson against the current; but one of the bridle lines yielded

a little; the caisson swung around, so that it was impossible to steer. The boat returned to the shore and the bridle lines were readjusted, and the boat, with her tow, moved again into the river; the engines of the boat were taxed to their full capacity, and more than an hour's time was spent in moving a half a mile against the current, but the feat was successfully accomplished, and early in the afternoon the caisson grounded on the bar, a little west of the site of the pier. I have always considered that Captain R. F. Woolfolk, who commanded the Northern Pacific transfer steamer No. 1, was entitled to very great credit for the manner in which he handled this heavy caisson on this occasion.

The caisson was then moored to the piles which had been driven for the purpose, and by taking advantage of the scour which the current made immediately around it, and with the assistance of a water jet, it was gradually drawn into place; on the 13th of August, it was in exact position.

The barge containing the pneumatic machinery was moored on the west side of the caisson. On the 15th of August, the concrete filling was begun. The air-lock was fitted in place, and on August 20th, air pressure was first put on, and the removal of the false bottom begun. On the 26th, it was discovered that the caisson had taken fire, smoke appearing around one of the bolts near the north end. The air pressure was at once let off, and the caisson flooded and kept flooded for 36 hours; when the pressure was restored, it was ascertained that no serious damage had been done by the fire, and special care was taken to prevent a recurrence of the accident. On the 29th of August, the concrete filling was completed.

The first stone of the masonry was laid on the 1st of September. The sand-bar, which had been forming east of this pier, was now dry for two-thirds of the distance from Pier II to the east shore. Two loading derricks had been set up on the shore of the river about 500 feet below the bridge line, and arrangements made to take stone on barges to the site of this pier; this it was now impossible to do. A track of two feet gauge was laid from the unloading derricks along the shore and thence across the sand-bar to the south end of the pier, the narrow channel between the shore and the sand-bar being crossed by a pile bridge. The stones were loaded by the derricks on small cars and drawn out by a horse to the pier, one horse being able to handle as much stone as the masons could lay up. The large derrick boat (shown on Plate 16) had been moored at the lower end of the pier, where there was water enough to float it, and with this derrick the stones were lifted from the cars and laid in the masonry.

The laying of the masonry and the sinking of the pier was carried on

as rapidly as circumstances would admit of. Very serious difficulty was experienced, however, in getting stone, the principal trouble being in the transportation between the quarries and Bismarck. Several days' time was lost from this cause at the most critical period, and it was considered just to give the contractors an additional allowance of \$1,000 to reimburse them for the actual loss incurred, owing to the failure of the railroad to transport the stone.

No obstructions of any consequence were encountered in the descent of the caisson, the material passed through being a very fine sand of quite uniform character; it continued fine to within a few inches of the surface of the clay, none of the coarse sand, which has generally been found below the fine sand in the foundations of bridges on the lower Missouri, being encountered.

On the 29th of September, the south end of the caisson struck the clay at an elevation of 1581. The surface of the clay was quite uneven, the extreme difference of elevation within the area of the caisson being 11 feet; about one-third of the surface was covered with boulders, which were generally of sandstone, and the space between them was filled with a fine gravel. The fact that the irregularities of the surface were repeated in the strata of clay showed that these irregularities were in the original formation, and not due to any wash of the river. The clay was all exceedingly hard, but a black stratum which was found over the whole area of the pier, about three feet below the surface, was especially so, and the whole foundation was carried through, or into, this black stratum; it was difficult to drive a pick much more than an inch into this clay. At first the clay was worked by picking it, and then breaking it over until it was reduced to a sort of coarse clay gravel, which could be pumped out with the sand pumps. This method, however, was abandoned on the 27th of October, and all the clay excavated after that date was passed out through the air-lock in sacks, which proved a more expeditious, as well as a much cleaner, method.

The masonry of the main shaft of the pier below the ice-breakers was completed on the 17th of October, and on the 19th the laying of masonry was suspended, five ice-breaker courses having been completed.

On the 9th of November, the cutting edge had reached the elevation 1568, and the sinking was discontinued. The cutting edge was nowhere less than 4 feet below the surface of the clay except for a short distance at the north-east corner, where a trench was excavated 2 feet deep and 3 feet wide, and carried around the corner, so that no portion of the foundation should be less than 4 feet below the surface of the clay. The position of

this trench and the natural surface of the clay as compared with the position of the caisson is shown in perspective on Plate 12.

The work of filling the working chamber with concrete was begun at 1 P. M. on the 13th of November. The weather had turned cold and a violent blizzard blew through the night, but a shelter was provided for the men, and the work was continued day and night without interruption till 7 P. M. on the 16th, when the filling was completed. The concrete was formed of Portland cement and sand, generally in the proportion of three parts of sand to one of cement, and was passed in through the supply shafts and hoppers. No stone was used in this concrete, it being considered that any economy which might result from its use would be more than offset by the delays and difficulties which would attend it. The air-lock was removed and the working shaft filled with concrete by the 21st of November.

The river had now closed for the winter; a spur track, connecting with the track leading to the winter transfer bridge, was laid on the east side of the pier; a derrick was erected, and on the 25th of November, the laying of masonry was resumed. The derrick had to be raised twice to enable it to finish the pier. On the 19th of November, the last stone was laid. In February the steel nosing plate was put on.

As an extra precaution, about 607 tons of riprap were thrown in on the east side of the pier, where the clay was lowest. After the completion of the bridge, in the high water season of 1883, a much larger quantity of riprap was thrown in on both sides of the pier, being dumped from the track on the bridge with chutes. The total amount of riprap placed about this pier is 5,200 tons.

The center of the caisson is north of the axis of the bridge; of the whole 74 feet of the length of the caisson, 24 feet 8 inches being south of the axis of the bridge, and 49 feet 4 inches north of it, the difference being due to the long rake of the ice-breaker of the pier. The weight per square foot on the down-stream end of the caisson is therefore considerably greater than the weight on the up-stream end; the greater penetration of the down-stream end into the clay accommodates this condition.

The details of the masonry and foundation of Pier II are shown on Plates 6 and 10. The daily rate of progress in sinking is shown graphically on Plate 13.

The weight of the pier and the pressure on the foundation for the section south of the axis of the bridge, and the section north of the axis of the bridge, and the whole assumed weight, are given in the following table:

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	South of Axis	North of Axis	Whole Pier
Caisson and concrete filling.	1,193,000	2,395,000	3,588,000
Masonry, 2,704.43 cubic yards.	4,277,000	7,404,000	11,681,000
	5,470,000	9,799,000	15,269,000
Superstructure and load, 400 ft. at 5,000 lbs.	1,000,000	1,000,000	2,000,000
	6,470,000	10,799,000	17,269,000
Deduct for immersion below elevation 1618.	1,446,000	3,064,000	4,510,000
	5,024,000	7,735,000	12,759,000
Area of base.	640 sq. ft.	1,284 sq. ft.	1,924 sq. ft.
Average pressure per square foot.	7,850 lbs.	6,024 lbs.	6,937 lbs.
Average pressure per square inch.	54.5 lbs.	41.8 lbs.	49 lbs.

PIER III

The sand-bar which had given so much trouble after the launch of the caisson for Pier II rendered it inexpedient to build the caisson for Pier III on the east side of the river; the material for this caisson was accordingly taken across the river, and the caisson was built on the sand-bar west of the site of Pier III.

The erection of this caisson was begun August 18th, 1881. It was precisely like the caisson for Pier II, the only difference being some slight changes in the lining plank of the air-chamber, where difficulty had been experienced in making tight joints in the former caisson. While this caisson was building, the channel shifted somewhat to the west and cut away the edge of the sand-bar, so that on the 12th of September it was necessary to move the caisson back a short distance. The first piles of the mooring clusters were driven on the 27th of September, and the pile-driving for the launching ways was begun on the 29th. The caisson was launched on the 21st of October, the launch being in every respect successful. The caisson was easily taken into position, and on the following day (October 22d) was accurately placed.

On the 26th of October, the work of putting concrete in the V-shaped spaces between the walls and over the roof of the working chamber was begun. Special directions had been given that the false bottom should be made strong enough to resist the pressure due to the 13 feet of water, so that the concrete might all be put in dry; but at five o'clock in the after-

noon of the 26th the false bottom broke in and the caisson settled and sank in 13 feet of water. This accident would have done comparatively little harm if the caisson had settled in position, but it swung around towards the east and settled eight feet out of place. No attempt was made to raise the caisson more than enough to clear the bottom of the river, so that it could be moved into place. At first it was moved without much difficulty, but the last two or three feet were accomplished very slowly, it being found necessary to place a bent on the up-stream side of the caisson, resting on the bottom of the river, and to lash heavy timbers to the top of the caisson, and by jacking on these timbers from the bent to raise the caisson enough to bring it into place. This operation consumed a week, and on the 2d of November, the caisson was brought into true position on the axis of the bridge, but was still a foot too far up stream. It was decided not to attempt to move it any farther, and on the following day (November 3d) the concrete work was resumed. The concrete was at first laid in the water, and was laid with one part of sand to one of cement, instead of two to one, to provide for the cement which would be washed out by the water. The concrete, when it reached above the surface of the water at one end, was carried around the caisson, filling the space next to the outer wall, but not the middle space over the roof of the working chamber. When the concrete had been brought above the surface of the water entirely around the caisson, the water was pumped out of the middle space; the laitance, which had thus been forced into the middle space, was taken out, and the remainder of the concrete filling made in the same manner as was originally intended. On November 12th, the concrete filling was completed, the air-lock was put on, and the concrete machinery was taken over to be used in filling the working chamber of Pier II. It was very fortunate that there was no greater delay, as the weather turned cold on the afternoon of the 13th, the ice began running, and on the 14th the river became blocked. But the machinery had been got in readiness for the work at Pier II, and no delay was experienced.

During the week ending November 19th, the temporary winter transfer bridge had been built; this bridge crossed from the sand-bar at Pier II to the sand-bar west of Pier III, passing Pier III 44 feet below the axis of the bridge; a spur track was built on piles connecting with this bridge, on which stone was received for the masonry. The derrick boat, which had already been taken from Pier II, was moored on the west side of Pier III, and as soon as the pressure was relieved at Pier II, the pneumatic machinery boat was brought over and moored on the west side of Pier III.

Air pressure was first put on on the 24th of November, and the laying of masonry was begun on the same day.

When the sinking began, the cutting edge of the caisson was at an average elevation of 1607.8. The material through which the caisson passed was entirely similar to that found at Pier II, being a fine sand throughout. On the 16th of December, the south-east corner of the caisson struck the clay at an elevation of 1581. It was decided not to attempt to break up and pump out this clay, but it was all passed out in sacks through the air-lock; the clay was of the same character as that found at Pier II, but the surface was more nearly uniform, and the strata more regular and horizontal. At an average depth of eight feet below the surface of the clay, a hard layer of marly rock, about three-quarters of an inch thick, was found, which extended over the whole foundation. On the 12th of January, the final settlement was made, and the cutting edge brought to an elevation of 1569, or 1 foot higher than the cutting edge of Pier II. As the caisson was a foot farther up stream than had been intended, and the greater weight of the foundation was at the lower end, a channel was cut, 2 feet deep, across the lower end of the caisson, which was chambered out 2 feet from the cutting edge, thus increasing the length of the foundation 2 feet in this direction. The position of this channel is shown on Plate 12.

The filling of the working chamber with concrete was begun at 9 A.M. on the 14th of January, and prosecuted without interruption, night and day, till 7 A.M. on the 17th, when it was completed. The working shaft was removed and the space occupied by it was filled with concrete on the 19th.

The laying of masonry was resumed on the 3d of February, and continued till the 4th of March, when it was abandoned to get out of the way of the ice break-up, the masonry having then been finished to the top of the ice-breaker. The derrick boat was left on the west side of the pier, and when the water rose on the 5th of April, at the break-up, it was swung around and moored below Pier IV, where it was left, hard aground, when the water fell; it was floated on the 15th of April. On the 15th of May, the laying of masonry was resumed, and on the 3d of June the last stone was set, finishing the masonry of the Bismarck Bridge. The steel nose-plate was not put on till January, 1883.

The details of the foundation and masonry of Pier III are shown on Plates 7 and 12. The daily progress of sinking is illustrated graphically on Plate 13.

The weight of Pier III is a trifle less than that of Pier II, the pier containing 2,650 cubic yards of masonry, whereas Pier II contains 2,704.4 cubic

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yards; the pressures on the foundation are essentially the same (though not quite as great) as those of Pier II.

PIER IV

The situation of Pier IV, 200 feet west of the eastern end of the dike, made it seem unnecessary to carry the foundation of this pier to the clay, which was here found at an elevation of 1544.7, or 36.3 feet deeper than at Piers II and III. The rectification of the river and the confinement of it between the dike and the east shore is an essential part of the plan of the Bismarck Bridge, and so long as this work is maintained there is no danger of scour at the site of Pier IV. It was considered that a first-rate pile foundation, thoroughly protected with riprap, would be ample for this pier, which in reality does not stand in the river, but some distance back from the shore line of the rectified river.

On the 15th of September, 1881, an excavation was begun at the site of this pier, which was carried down until the sand became too wet for further work. On the 29th of September, the construction of a curb was begun in this excavation; the walls of this curb were built solid of 12 by 12 inch pine timber, and planked on the outside with one thickness of vertical planking, the planking for 4 feet from each corner being of oak, and the remainder of pine; this change from the specifications was adopted in consequence of the difficulty of getting oak plank. This curb was finished on the 14th of October. A pump was rigged at the south-east corner of the curb, and excavating was begun in it on the 18th of October; the sand was placed on platforms resting on timbers laid across the top of the curb, so as to get the necessary weight to force it down. This work was delayed by a series of small mishaps, due principally to the fact that the greater importance of other parts of the work at this time made it necessary to put foundation IV in the hands of the least competent foreman. On the 11th of October, the sinking of this curb was completed, the cutting edge being at an elevation of 1610; it afterward settled to 1609.4 during pile driving.

As the piles for this foundation had to be driven in the sand, it was decided that too much delay would occur from the use of the ordinary pile driver, and a steam pile hammer was purchased by the railroad company and supplied to the contractors without charge for its use; the boiler power furnished to run this steam pile hammer proved insufficient, and steam was supplied by a locomotive, which was stationed on a track laid along-side. The first pile was driven on the 21st of November, but five days were con-

sumed in attempting to use the small boilers on hand; on the 26th, the pile driving was fairly begun, with a locomotive to make steam, and continued to the 30th, when this engine was taken away. A second engine was furnished on the 3d of December, and the driving continued, without interruption, till the 20th, when the locomotive was disabled by the burning of the round house at Bismarck, in which it was kept over night. Another locomotive was furnished on the 22d, and the pile driving was completed on the 27th of December. A full record of the driving of every pile in this foundation was kept; this record is given in Appendix E.

On the 15th of December, the curb was pumped out, and the cutting off of the piles was begun; they were cut off at elevation 1612.8. It was found necessary to drive some sheet piling in the north-east corner, to prevent the flow of sand. The first timbers for the grillage were placed on the 1st of January, 1882, and the concrete filling in the grillage was begun on the 7th of January; the grillage and concrete were completed January the 11th. This concrete was made of Rosendale cement and sand in the proportion of two of sand to one of cement. On the 19th of January, the laying of masonry was begun. A derrick was set up on the west side of the pier, and the stone was received on cars on a track laid on the west side of the pier. After the masonry had been brought above the top of the curb, the space between the masonry and the curb was filled with concrete; this concrete was made of Rosendale cement and sand, with two parts of sand to one of cement, and a quantity of rubble-stone was worked into it; it was mixed in the same manner as the other concrete. The laying of masonry was suspended on the 24th of March, so as to keep clear of the ice break-up, and resumed on the 19th of April. The pier was finished May 12th, 1882.

The details of the foundation and masonry of Pier IV are shown on Plate 8.

The weight of Pier IV and the pressure upon the foundation are as follows:

28,000 ft. B. M. timber in curb at 4 pounds, - - -	112,000 lbs.
15,000 " " oak in grillage at 5 " - - -	75,000 "
264 cub. yds. concrete at 3.510 " - - -	926,640 "
1093.3 " " masonry at 4.330 " - - -	4,733,989 "
	5,847,629 lbs.
257 feet superstructure and load at 5,000 pounds, - - -	1,285,000 "
	7,132,629 lbs.

Deduct for immersion below 1618, 11,390 cub. ft.
at 62½ pounds, - - - - - 711,875 lbs.

Net weight, - - - - - 6,420,754 lbs.

Number of piles, - - - - - 161.

Average weight per pile, - - - 39,880 pounds.

As the concrete filling in the grillage is in direct contact with the sand in which the piles were driven, the actual pressure per pile is considerably less than these estimates show.

After the completion of Pier IV, 4,924 tons of riprap were placed around it, the greater part of this being on the east side, the riprap finishing at the elevation 1645, and being given a slope of two horizontal to one vertical towards the river. The entire space under the west approach span, between Pier IV and the Cushing pier, was filled with earth to the same elevation (1645), the material for this embankment being borrowed from the sand-bar. The slopes were ripped to prevent any wash from water which might overflow the bar, and to prevent wastage by winds; the up-stream side was connected with a clay embankment built to protect the trestle, which will be described in connection with the approaches. As the action of a few summer floods will raise the level of this sand-bar until it becomes converted into bottom land, it is not likely that it will be much exposed to the action of the water, excepting during ice floods, when it will be frozen.

MASONRY

No stone suitable for masonry has been found anywhere in northern Dakota, and the nearest available quarries were the granite quarries, in the neighborhood of Sauk Rapids, in Minnesota. The stone furnished by these quarries is of excellent character, and all that could be desired for heavy work, like the piers of the Bismarck Bridge; the principal objection was the great distance (about 400 miles) from the bridge site.

The first stone used was quarried near Watab station; this quarry contained two varieties of granite, one red and one gray, both excellent stone, the red being very handsome; it proved, however, a very unsatisfactory quarry to work, being badly broken up by "cutters," so that not over one-third of the whole rock quarried was available for dimension work. The stone from this quarry was used in the lower courses of Piers I and IV, and in Pier II below the top of the ice-breaker; that in Piers I and IV is all below the ground, and the only Watab stone which is now visible (except a

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single stone on the east side of Pier I, and the stone in the east abutment) is in the ice-breaker courses of Pier II.

It soon became evident that the Watab quarry would not furnish stone for the work, and in June, 1881, a second quarry, known as the "Rock Island Quarry," was opened a few miles below Sauk Rapids, adjoining the track of the St. Paul, Minneapolis & Manitoba Railway. This quarry proved of excellent character; the stone was a uniform blue-gray granite, which quarried in good shape and, though very hard, was worked with little waste. All the dimension stone for the Bismarck Bridge, excepting as already stated, was obtained from this quarry.

The dimension work was laid up in Portland cement mortar, generally mixed in the proportions of two parts of sand to one of cement; the backing was laid in Rosendale cement, mixed in the same proportions. The whole work above ground or water was pointed with a Portland cement mortar, consisting of two parts of fine sand to one of cement, which was driven into the joints with a flat-edged calking-iron, and afterwards wetted down to prevent drying out.

There were used in this work 7,649 barrels of Portland cement, and 3,198 barrels of American cement; of the Portland cement, 7,529 barrels were of the brand manufactured by Alsen & Sons, of Itzehoe, near Hamburg, Germany, and of the American cement, 2,441 barrels were Rosendale cement, manufactured by F. O. Norton. The greater portion of the Portland cement was used in concrete. The actual distribution of the cement used is shown in Appendix F.

Piers I and IV, which are not in the current of the river, and are buried in the ground to a height above the great ice flood of 1881, are without ice-breakers; these piers measure 8 feet thick and 27 feet long between shoulders, and have semicircular ends, finishing 35 feet over all, under the coping; they are built with a batter of $\frac{1}{4}$ inch to the foot, throughout.

Piers II and III, which are in the channel of the river, measure 10 feet thick, 25 feet long between shoulders, and 35 feet long over all, under the coping; they are built with a batter of $\frac{1}{4}$ inch to the foot throughout, except on the up-stream cut-water; on the down-stream end of the pier the semicircular starling is carried from the top of the pier to the foundation, but the up-stream side is built with a long raking ice-breaker, the section of the starling being formed by two circular arcs, each having a radius equal to the thickness of the pier, and the shoulder line being given a batter of 8 inches in a foot; the entire ice-breaker is 30 feet high, and the rake on the shoulder line 20 feet. All the dimension stones for the height of the ice-

breaker are doweled into those of the course below, with dowels of 1 $\frac{1}{2}$ -inch iron, extending 6 inches into each course. The cut-water is plated with a plate of $\frac{1}{4}$ -inch steel, extending 3 feet on each side of the nose; this plate is fastened to the masonry by anchor bolts with countersunk heads, and has a smooth, flush surface on the outside, all the splice plates being on the under side; the space between this plate and the masonry of Pier II was packed with Portland cement mortar carefully rammed, but the ice break-up of 1882 destroyed this filling so that it worked out, and the space was subsequently packed with rust cement, which was also used in packing under the plate on Pier III.

The total amount of masonry and concrete in the Bismarck Bridge is shown in the following table:

	Masonry	Concrete	Total
East Abutment.....	70.0	23.0	93.0
Pier I.....	952.1	779.3	1,731.4
Pier II.....	2,704.6	847.1	3,551.7
Pier III.....	2,653.0	859.5	3,512.5
Pier IV.....	1,090.3	264.0	1,354.3
Cushing Pier.....	1.6	37.0	38.6
Total.....	7,471.6	2,809.9	10,281.5

The plans of the masonry are given on Plates 5, 6, 7, 8 and 9, these plates showing the work as actually executed, every stone conforming in size to the actual work.

VI

SUPERSTRUCTURE

The superstructure of the Bismarck Bridge consists of three through spans and two short deck spans in the approaches, the western end of the west deck span being supported on an iron bent, which is also included in the superstructure. The entire superstructure was manufactured by the pound, from designs prepared by the engineer of the bridge, complete detail shop drawings being furnished to the contractor.

The three through spans are 400 feet long between centers of end pins; they are of the double intersection Whipple type. The two deck spans are 113 feet long between centers of end pins; they are of the inverted bowstring or fish-belly pattern, this peculiar form being adopted to keep the iron-work out of the way of the slope of the embankments of the approaches.

On the 17th of January, 1881, a circular was addressed to six prominent bridge manufacturers, inviting them to bid on the construction of the superstructure of the Bismarck Bridge. Printed specifications accompanied the invitation. These specifications are given in Appendix G.

In response to this invitation, proposals were sent in by the four following manufacturers: The Delaware Bridge Company, The Detroit Bridge & Iron Works, Messrs. Kellogg & Maurice, The Keystone Bridge Company.

These proposals were opened in New York on the 2d of February, 1881. There was little difference in the prices bid for the manufactured material, the lowest bid being that of Messrs. Kellogg & Maurice. The bid for erection, however, of the Detroit Bridge & Iron Works was much lower than that of any other party, and the work was awarded to this company, as the lowest bidder.

THROUGH SPANS

The trusses of the 400-feet through spans are divided into 16 panels of 25 feet each; they are of the double system Whipple type, with inclined end posts, are 50 feet deep, and spaced 22 feet between centers; they are in many respects identical with the two spans of the same length in the Platts-mouth Bridge, such modifications having been introduced as the experience obtained during the construction of the Platts-mouth Bridge seemed to recommend. The top chords, end posts, bolsters, rollers, bearing plates, pins and the eye-bars in the ten central panels of the bottom chords are of steel; all other parts are of wrought iron, excepting the heavy wall plates resting on the masonry, the filling rings and washers and the ornamental work, which are cast iron. The floor is placed above the bottom chord, the floor beams being riveted to the vertical posts, thus increasing the vertical stiffness of the structure and reducing the apparent height to about 45 feet. The main and counter ties are made in two lengths and coupled on a pin, which passes through the center of each vertical post, this arrangement sustaining the tie from deflection and stiffening the vertical post against flexure. The end posts are stiffened by a horizontal strut connecting them at the center with

the stiff center of the first vertical post, this horizontal strut being itself stiffened by pin connections with the vertical suspender and the first set of main ties. The vertical posts are connected transversely by struts which are attached to the central pins by small pins which pass through the ends of the strut and through the main pins, and on which is connected a set of transverse diagonal rods, which reach to the top lateral struts. Each pair of vertical posts is thus united into a stiff bent, with diagonal bracing in the upper half and a rigid floor connection at the bottom. The inclined end posts are stiffened by a wrought iron portal, consisting of an angle iron lattice-work above the center, and with sides extending down the posts to the floor level. The lateral rods are everywhere in pairs. The connections of the top lateral rods and of the transverse rods are on small pins, which pass through the main pins. The bottom lateral rods are connected on small pins, which pass through lugs and plates riveted to the floor beams.

The top chords and end posts are formed of steel plates and angles, each member consisting of two side plates, four angles, a cover plate and two balance plates on the under side, while additional section is secured in the central panels by filling plates on each side between the angles; the members are laced on the under side, the amount of steel in the balance plates and lacing being almost exactly the same as in the cover plate. In computing the strength of each member, the central portion of the cover plate was considered as taking the place of a lacing, and only an amount of the cover plate equal in section to the two balance plates was used in estimating the amount of material available to resist compression; thus the top chord and end post pieces were practically symmetrical in section; the pins were placed on the center line, and the useful material was the same above and below; this symmetrical form is considered very important in a compression member. The vertical posts are formed of two channels with the flanges turned outwards, laced; the channels composing the nine central posts are rolled in a single length; those of the other four posts, which are heavier, are in two lengths, spliced at the center. The lateral and intermediate struts are made of two channels, laced on both sides. The lateral connections are all made on turned pins, and fitted with the same care and accuracy as the main pins. The connections of the end posts with the top chords and with the bolsters are on pins, the material being so distributed that the compression bearings on the two sides of the pins lap by each other, thus relieving the pins from bending or shearing strains. The two panels at each end of the bottom chord are made in a stiff member, composed of two 12-inch channels, laced above and below, this form of chord being adopted here

to resist any possible compression which might be thrown into the bottom chord by an over adjustment of the heavy lateral rods, and to support the end post against any blow which it might receive from a derailed train. The third panel from each end of the bottom chord is of iron eye-bars. The expansion rollers run on bed-plates formed of steel rails riveted to a bottom plate and faced to form a seat to receive the rollers, the spaces between the heads of the rails allowing the dust to pass freely into the larger opening below. The details of these spans are given on Plates 20 to 24.

It was thought best not to proportion this structure for the weight of any particular locomotive or cars now in actual use, but for general conditions, which, while including the heaviest class of rolling stock which is likely to run over the bridge, should not be limited to precise types of locomotives or cars that are liable to be changed at almost any time. The three 400-foot spans are designed to carry a train weighing 2,000 pounds per lineal foot, preceded by two locomotives, each weighing 150,000 pounds, on 50 feet, the excess of weight of the locomotives over the ordinary weight being supposed to be concentrated on the first and third panel points covered by the load; that is, the trusses are proportioned to carry a moving load of the following amounts on successive panel points covered by the load, viz.: 100,000, 50,000, 100,000, 50,000, 50,000, 50,000, &c. The weights on a single truss would be 50,000, 25,000, 50,000, 25,000, 25,000, 25,000, &c. It will be observed that this throws the entire excessive weight of the locomotives on the same system of bracing in the web. This load is equivalent to a train of modern box cars 33 feet long inside, each weighing 25,000 pounds, and loaded with 45,000 pounds, preceded by two consolidation locomotives of the heaviest type, with further provision for the concentration of locomotive weights in a way that adds essentially to the strains on the web.

The strain produced by this moving load, and the strain due to the dead load of the structure, as computed from the actual shop weights, applied at the several panel points, and not uniformly distributed throughout, are shown in the strain sheet on Plate 26. The maximum strain produced by this load was intended to be limited to 15,000 pounds per square inch on the balanced section of the steel compression members of the top chord, and to 14,000 pounds per square inch on the steel tension members of the bottom chord, and on iron tension members to 10,000 pounds per square inch. The weights of the superstructure were, however, a little more than was expected, and under certain extreme conditions these strains are exceeded, the excess, however, being never more than about 1,000 pounds

per square inch above that originally intended. In Appendix I the exact strains are given in detail, those of the dead load being taken from actual shop weights as applied at each panel point, and not from any assumed or averaged weights. The same sheet shows what the strains would have been under an extraordinarily heavy specification, such as has been used for some later bridges. It will be seen that the strains produced by this extraordinary condition are within usual limits, excepting in the central panels of the chords, and that in these panels they do not exceed the working strains which have been sometimes recommended for steel members.

The pins for the main trusses are all of uniform section, 5 inches in diameter. The packing was carefully studied out, so as in no instance to produce a bending strain on the extreme fibres exceeding 20,000 lbs. per square inch, the strains on each bar being supposed to be concentrated on its center.* The maximum bearing strain allowed on the pins is 20,000 pounds per square inch, where both surfaces are of steel. The greatest length of pin outside of the post is $7\frac{1}{2}$ inches, or $1\frac{1}{4}$ times the diameter of the pin. The expansion rollers are $2\frac{1}{4}$ inches in diameter, and the greatest weight which they have to carry is 1,289 pounds per lineal inch; they are set in frames which can be taken apart from the outside for cleaning.

The top lateral system is proportioned to resist a wind strain of 300 pounds per lineal foot, and the bottom lateral system a wind strain of 500 pounds per lineal foot, the whole of each being taken as a moving load; the strains which these pressures are allowed to produce are one-half greater than those allowed to the weight carried, 15,000 pounds per square inch being the maximum tension allowed on wrought iron.

*Owing to an error, the inside bars on the center pins of the two eastern spans were misplaced; the pair of bars which should have been outside being placed inside those which should have been inside; this produces a theoretical bending strain of about 30,000 pounds to the inch for a length not exceeding the diameter of the pin, the distance between the two center bars, as packed, being less than 2 inches. Experiments have shown that steel pins are more than twice as strong to resist a permanent set from bending as from pins, and this strain is not more than double the strain which good practice allows on iron pins; moreover, the only bad effect which the bending of a pin can have (except in very extreme cases, where the pin is loosely packed) is to distribute the strains unequally on the several bars attaching to the pin. In this particular case, the excessive bending strain exists for so short a distance that it can hardly have any effect in distorting the pin; and, moreover, the arrangement of the bars, there being precisely the same section of bars on each side, outside and inside, is such that it is hardly possible that the strain should be unequally distributed; beyond this, I have become fully impressed with the fact that the bending strains really existing in a well-packed pin, where several bars, pulling in opposite directions, are in immediate contact with each other, are very much less than any theoretical calculations of the kind named would show; in fact, the slightest bending of the pin must throw the point of application of the two bars pulling in opposite directions, towards each other, until the strain on the pin is reduced entirely to a shear, all bending being eliminated. As the error in these four pins is a theoretical one purely, and the irregularities which it can produce are certainly no greater than those which would be produced by the varying modulus of elasticity in different eye bars, it was not thought expedient to change the packing of the bars; this can be done now, if it is thought best, but I do not believe that any practical weakness could be found at this point, even if the trusses were tested with a sufficient load to break them down. In the western span this error was corrected.

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The iron floor system of the through spans consists of two lines of stringers, placed 9 feet between centers, attached to transverse floor beams at each panel point. The attachment between the stringers and the floor beams is by angle irons riveted to the web of each. The stringers also rest on a wrought iron step built on the floor beam, this being an extra provision, which is not considered in calculating the strength of the connection. The end floor beams rest upon the bolsters and are riveted to them; the next set of floor beams is suspended by long verticals from the pin at the top of the end post. The other floor beams are riveted to the vertical posts, the connection being made through angle irons which are also riveted to the webs of the beams; the beams also rest on top of the pin plates, being accurately fitted thereto, but this bearing is not estimated in calculating the strength of the connection.

The stringers are proportioned to carry a moving load of 50,000 pounds each, uniformly distributed over a length of 20 feet (100,000 pounds on 20 feet of the track), besides the weight of the timber floor and of the stringers. Each stringer consists of a web plate 30 by $\frac{1}{2}$ inches, and four angle irons, 5 by $3\frac{1}{2}$ by $\frac{1}{2}$ inches. Each pair of stringers is stiffened at the center by a riveted angle iron frame with diagonal bracing of 1-inch rods, screwed up against wrought iron skew-backs, this bracing being entirely independent of and additional to the regular lateral bracing of the trusses.

Each pair of stringers, with these connections, weighs 6,800 pounds. The estimated maximum bending strain on these stringers is less than 8,000 pounds per square inch of cross section in the extreme fibers, the stringer being calculated as a beam on the principle of the moment of inertia. The assumed moving load produces a strain 17 per cent. greater than that produced by the ordinary pattern of consolidation locomotive. Detailed calculations of the strength of these stringers are given in Appendix H. The flanges of the stringers of the end panels, which are slightly longer than the others, are made of angles $\frac{1}{8}$ of an inch thick.

The floor beams are formed of a web plate 39 by $\frac{1}{2}$ inches, with four angle irons $3\frac{1}{2}$ by 5 by $\frac{1}{2}$ inches, and cover plates 12 by $\frac{1}{2}$ inches, 14 feet long; on the end floor beams, which carry only half a panel length, the cover plate is omitted. These floor beams are calculated to carry a moving load of 50,000 pounds at each stringer connection (100,000 pounds per floor beam), besides the weight of the floor. The maximum bending strain on the extreme fibers of these beams is less than 8,000 pounds per square inch. The details of this calculation are given in Appendix H.

The expansion rollers for the east and central spans are placed on Pier II; those for the west span on Pier III.

In proportioning the 400-foot spans, it was considered important to use steel in all positions where reduction of dead weight would materially reduce the strains in the structure, but it was known that the difficulties in procuring a satisfactory steel were such that it was unwise to attempt to use any more of this material than necessary. The experience with the Plattsburgh Bridge had shown that a steel could be obtained, with comparatively little difficulty, which was admirably fitted to resist compression in members of moderate length, but we are still without accurate data to determine the strength of steel compression members of such length that their yielding is a matter of flexure rather than of compression. As regarded tension members, the fact was established that steel eye-bars could be made which would show a very uniform modulus of elasticity, within safe working limits, and an elastic limit fully one-half higher per square inch than could be developed in iron eye-bars of the same working strength, but it had not yet been found practicable to get steel eye-bars of a uniform ultimate strength, or which would develop anything like a uniform elongation before fracture. Under these circumstances, it was thought best to limit the use of steel in compression to the end posts and top chords, where the length does not exceed sixteen times the least transverse dimension, and to limit the use of steel in tension to the ten central panels of the bottom chord, where there are never less than four bars side by side, where the strains are applied slowly, and where a high elastic limit and a uniform modulus of elasticity are needed, the ultimate strength of the material being of comparatively little importance. The excellent results which had been obtained on steel bearing surfaces and in tests of steel pins, made it expedient to make all the pins in the structure, as well as the rollers, bearing plates, etc., of steel. The difficulties which were experienced in the manufacture of steel-work showed that these limitations had been wisely made.

The weights of iron and steel in the 400-foot spans are as follows:

	Three Spans		Average per Span
	Pounds	Pounds	Pounds
Steel.....		1,046,390	348,797
Wrought Iron in Trusses.....	1,335,755		
" " Floor.....	466,591		
Total Wrought Iron.....		1,802,346	600,782
Cast Iron.....		77,331	25,777
Total.....		2,926,067	975,356

DECK SPANS

The two deck spans measure 113 feet between centers of end pins, divided into seven panels of equal length. They are of the inverted bow-string pattern, with a curved lower chord. The trusses are placed 9 feet between centers, and the top chord is apportioned as a beam to carry the weights of the floor between panel points. The ties rest directly on the top chord, the distance between the chords being the same as that between the stringers of the through spans.

The peculiar form of truss here used was adopted because there would be no danger of the iron coming in contact with the slope of the embankment; it makes a very safe and serviceable truss, but as it is necessary to put adjustments in all the diagonals, it is not a form of structure which would generally be preferred.

The deck spans are proportioned to carry a moving load of 80,000, 40,000, 40,000, 80,000, 40,000, 40,000 pounds on successive panel points. The strain sheet for these trusses is given on Plate 26.

The details of these trusses are shown on Plates 17 and 18.

The west end of the west approach span is supported by an iron bent, which is intended to be ultimately buried in the embankment when the timber trestle of the west approach is filled. The truss is bolted rigidly to the top of this bent, and the end on Pier IV has expansion rollers, the end pins at the east end being connected with the end floor-beam of the western through span by an arrangement which allows the necessary expansion for changes in temperature, but which would hold the truss secure in case of the iron bent being relieved of the longitudinal support which the wooden trestle now gives it.

The weights of steel and iron in the deck spans are given in the following table:

	Two Spans	Average per Span
	Pounds	Pounds
Steel.....	5,750	2,875
Wrought Iron.....	177,908	88,954
Cast Iron.....	11,372	5,686
Total.....	195,030	97,515
Iron Bent.....	13,514	
Total.....	208,544	

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MANUFACTURE

With the exception of some of the plate iron which was rolled at Cleveland, the iron and steel for the Bismarck Bridge were rolled by different parties in Pittsburgh; the material was then shipped to Detroit and there manufactured into finished shape at the shops of the Detroit Bridge & Iron Works.

Two changes were allowed in the specifications relating to iron work. First: The wide plates for the floor beams were accepted when the test samples developed an elongation of 8 per cent., instead of 10 per cent. as required by the original specifications. Second: The contractor was allowed to use iron eye-bars manufactured by the Kloman process, a series of special experiments on full-sized bars having shown that an entirely satisfactory bar could be made in this way. The manufacture of the steel proved a source of very great trouble and delay, the difficulties being due in part to the inexperience of the manufacturers, and in part to other circumstances which were wholly inexcusable.

The contractors were very much behindhand in the manufacture of the superstructure, and were not ready to begin the erection of the long spans till the summer of 1882, or about a year and a half after the award of the contract.

STEEL

On the awarding of the contract to them, the Detroit Bridge & Iron Works arranged with Andrew Kloman, of Pittsburgh, to furnish the steel. Andrew Kloman himself had died some months before, and the business was then carried on by his two sons as "testamentary trustees." They proposed to have the steel made by the Pittsburgh Bessemer Steel Company, Limited, a new concern, whose works had been designed by Mr. Andrew Kloman (who would have had charge of them if he had lived); and to roll the plates, angles and eye-bars in their mill in the lower part of Allegheny City. This source of steel supply proved entirely unsatisfactory.

The specifications required that a sample bar should be rolled from a small ingot taken from every charge, and that if this sample failed to meet the requirements of the specifications, the whole charge should be rejected. The first lot of sample test bars was furnished to the inspector on April 20th, 1881. They proved to be very irregular in character, showing that the steel was wholly unsuitable for the purposes for which it was intended. The next set of samples, which was given to the inspector on May 5th, 1881, proved no better. Between April 20th, 1881, and November 14th, 1881, 235 sample bars, made from 235 melts made by the Pittsburgh Bessemer Steel Company,

Limited, were tested, of which only 37 met the requirements of the specifications; they showed very great irregularities, the elastic limit ranging from 49,010 to 109,766, and the ultimate strength from 71,970 to 161,986; moreover these irregularities seemed in nowise dependent on the reported composition of the steel, a steel reported as an 0.18 steel giving an ultimate strength of 161,986. A subsequent analysis of this sample showed that instead of being an 0.18 carbon steel, as reported by the manufacturers, it was really a 0.56 carbon steel. Of the 37 melts which were accepted on the sample test, 34 were of the higher steel for compression, and 3 of the lower steel for tension. A few of the accepted melts of the compression steel were rolled into angles, but the low tension steel, which was accepted by the sample, was rejected in the ingots, which were honeycombed with blow holes and very defective. The total amount of steel manufactured by the Pittsburgh Bessemer Steel Company, Limited, and used in the Bismarck Bridge, was 58 tons.

The management of the Pittsburgh Bessemer Steel Company, Limited, explained their failure to make the steel by an accident which occurred to their chemist when the first charge was blown, and which completely disabled him for several months. The concern was a new one, and to make a uniform product of Bessemer steel, suitable for bridge purposes, requires no ordinary skill; but it was evident that the company made little or no effort to furnish the material according to specifications, finding that they could make more profit by making steel rails. This fact was fully proved when, on inquiry, it was found that the ingots of a few melts which were accepted had already been rolled into rails without waiting for the inspector's report.

On the 22d of July, 1881, I met Mr. Willard S. Pope, president of the Detroit Bridge & Iron Works, at Pittsburgh, and after a very amusing interview with three of the directors of the Pittsburgh Bessemer Steel Company, Limited, who successively explained their failure to make the steel on entirely different theories, which were absolutely inconsistent with each other, it was agreed that no further attempt should be made to make steel for the tension members and pins by the Bessemer process, but that steel for these purposes should be made by the open hearth process. On this day, I addressed the following letter to Mr. Pope:

WILLARD S. POPE, Esq.,

President Detroit Bridge & Iron Works.

DEAR SIR,—I will consent to the following modifications in the requirements for the steel for the Bismarck Bridge:

1st. The steel for eye-bars and pins shall be manufactured by the open hearth process, and shall agree in all respects with the requirements of the specifications, except that in steel intended for eye-bars the elastic limit shall have a range not exceeding 5,000 pounds, the minimum of which range shall not be less than 40,000 pounds, and the maximum of which shall not exceed 50,000 pounds.

2d. On condition of the eye-bars and pin steel being made as above, steel will be accepted for compression members which meets the following requirements. The elastic limit shall not be less than 50,000 pounds, nor more than 60,000 pounds, and the ultimate strength shall not be less than 80,000 pounds per square inch; the test bar shall elongate at least 14 per cent. uniformly before breaking, and shall have a reduced area of 30 per cent. at the point of fracture; the modulus of elasticity shall not be less than 28,000,000 pounds, nor more than 30,000,000 pounds per square inch; the other requirements to remain as in the specifications. These requirements are not intended to exclude any steel which conforms strictly to the printed specifications, but the right is reserved to reject any steel in which the modulus is exceptionally irregular.

Yours truly,

GEO. S. MORISON,

Eng. and Supt. Bismarck Bridge.

At this time all the older steel works were full, and the orders for open hearth steel were placed with the Spang Steel & Iron Company, Limited, a new concern, whose works are located on the west bank of the Allegheny River, at Etna Station, a short distance beyond the Pittsburgh city limits.

The open hearth plant of the Spang Steel & Iron Company, Limited, consisted of an ordinary Siemens-Martin furnace of 9 tons capacity, and a Pernot furnace of 9 tons capacity. The first samples of steel were given to the inspector on the 8th day of August. Although the rejections still formed a considerable percentage of the whole amount of steel made, the state of affairs was very different from that at the works of the Pittsburgh Bessemer Steel Company, Limited. The manufacturers were evidently doing their best, and the delays were due to the starting of an entirely new lot of machinery with, to some extent, untried hands.

The pretense of trying to have the compression steel made by the Pittsburgh Bessemer Steel Company, Limited, was continued till October 14th, when it was abandoned, and the order for this, as well as for the ten-

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sion steel, was placed with the Spang Steel & Iron Company, Limited, the whole to be made by the open hearth process.

A full record of all the sample tests made was kept by the inspector. A record of the tests of open-hearth steel is given in Appendix J. The record of the tests of Bessemer steel, which was valuable simply as showing how irregular a product can be made, is not given. Out of a total of 152 melts of compression steel tested, 117 were accepted; from these accepted melts 230.8 tons of finished material were accepted, being an average of 1.9 tons per melt. Of 120 melts of tension steel inspected 47 were accepted. From these accepted melts 207½ tons of finished product were accepted, being an average of 4.4 tons for each accepted melt.

The angles were rolled by the Klomans at their mill in Allegheny; the pin steel was hammered at the same mill, and the plates were rolled in a universal mill, at the works of the Spang Steel & Iron Company, Limited. The ingots for the universal mill plates were cast in the shape of large flat slabs of about the same width as the finished plate; much material was wasted and time lost in ascertaining the best form of ingot molds, it being found that ingots which had a draft of ¼ an inch in their length would not spread enough under the rolls to give smooth finished edges. The first shipment of compression steel was made from Pittsburgh on June 13th, 1881, and the last shipment June 26th, 1882.

The eye-bars were rolled by the Kloman patent process in a universal mill, which is specially designed for this work, the mill being reversed while the metal is still between the rolls, leaving enlarged ends which were subsequently hammered into shape. The class of steel selected for the tension members was much lower than that which had previously been used in steel bridges, and it was believed that this soft steel would not require annealing. The specifications required the contractors to furnish three additional bars of every size used in the bridge, which were to be tested at such place as the engineer should select. These bars were not furnished promptly, and after they had been selected by the inspector, the first lot of them was held at Pittsburgh instead of being shipped promptly to Watertown. A preliminary test had been made of some small steel bars rolled specially for the purpose, which indicated that annealing would not be necessary. The results of the tests at Watertown, however, showed that annealing rendered the steel decidedly more ductile, and all of the largest size of bars, 6½ by 1½ inches, were required to be annealed. This annealing was done by placing the bars side by side on small brick piers, building a wood fire under them, and covering the whole with sawdust; the bars

were heated to a uniform heat, and subsequently covered over and allowed to cool slowly.

The whole number of bars tested in the Emery testing machine, at the United States Arsenal at Watertown, Mass., was 15, of which 5 broke in the head; they showed a very uniform modulus of elasticity, a reasonably uniform elastic limit, but a decided variation in their ultimate strength; while, with one exception, the extension before breaking corresponded quite closely with the ultimate strength. The exception was in bar No. 1822, which was of a very high steel that had accidentally been rolled into an eye-bar; this bar broke in the head, the strength of the material in the body of the bar not being developed. Its behavior, however, within working limits was so nearly uniform with the other bars as to show that an occasional high steel bar can be placed among low steel bars without disturbing the workings of the several bars in a bridge. A test (No. 1839) was made of a bar one-half of which had been annealed; this bar broke first in the unannealed head, was again clamped in the machine and broke a second time in the annealed part of the body of the bar; was tested a third time, and broke in the unannealed part of the body of the bar; it did not break at the center of the bar, where the annealing terminated; it showed that before the elastic limit was passed there was no material variation in the behavior of the annealed and the unannealed portion, but that after the elastic limit was passed the annealed portion stretched very much more rapidly than the unannealed portion.

A full record of the tests made at the Watertown Arsenal is given in Appendix K. Of the bars tested there, bars No. 18 and 1930 were annealed, and bar No. 1839 was annealed for half its length.

Analyses were made for the six principal hardeners in each of the eighteen bars tested at Watertown by two different chemists, and the results of these analyses, together with a brief summary of the mechanical tests, are given in Appendix L. All the sample tests were made by Mr. W. F. Zimmermann, who also inspected the iron and steel at the mills. The elongations under strain were measured with an electric micrometer, and curves showing the behavior of every sample were plotted and preserved.

The tests of full sized bars showed that the material did not conform, in the matters of ultimate strength and elongation before breaking, to the requirements of the specifications; its behavior, however, below the elastic limit was exceedingly satisfactory; as the use of steel eye-bars had been confined to positions in which the ultimate strength was of comparatively little importance, the material was accepted.

ERECTION

The dirt which was wasted from the big cut in the east approach was deposited so as to make a yard level with the grade on the bridge, between the bluff and the bridge. A track connecting with the approach track was laid along the face of the bluff and through this yard, forming a very convenient place to receive the superstructure material. The iron and steel for the superstructure and much of the false work material was run down on the track through this yard, where it was unloaded on skidways.

The east approach span was erected in April, 1882, but not completed till May 9th, the work being delayed by an error in one set of chord bars. The false work for the west approach span was raised early in May, but was blown down by a gale before any iron had been placed upon it; this span was finished on the 3d of June.

The three main spans were erected with a traveler, without the use of upper false work; this traveler was built on the level ground of the material yard, just back of the east abutment. It was erected in April, 1882. It was 61 feet 6 inches high over all, 30 feet long, and ran upon two lines of rails 27 feet 6 inches apart, spanning the entire iron-work; at each end it was fitted with a movable bracing of iron diagonal rods and cross timbers, which could be taken out; while at work, this bracing was kept in at one side, but when it became necessary to move it past the iron-work already erected, the entire temporary bracing was removed. This traveler reached over one panel, so that four posts could be erected and the top chord sections put on and the couplings made, without moving it. The traveler was simply a derrick which carried the attachments for the lines used in handling the iron and steel, these lines being led to a pair of hoisting engines, which were placed on a low flat car (Michigan Central Railroad car No. 3615), that ran on a track placed on the false works; this same track was used to run out material.

The false works used for the erection of the two easterly channel spans consisted of three spans of Howe truss, supported by temporary timber piers and resting on harnesses placed on Piers II and III. These trusses were placed 25 feet between centers. The false works used for the westerly span consisted of one span of Howe truss at the east end and 260 feet of timber trestle, resting on piles.

The five temporary timber piers were designated as cribs A, B, C, D and E, A being the easterly one. The original plan was to build them of piles, surrounded by crib work to hold the piles together and resist the scour of the river; for this reason, and to distinguish them from the main piers, they were designated as cribs. When the work was done, it was found neces-

sary to use this crib work only at B and C. Each temporary pier contained 32 piles, which were cut off a few feet above the water and surmounted by timber bents. At B and C these piles were surrounded by crib work of pine plank laid flat and filled with sand-bags and riprap.

Pile driving for Crib A was begun on June 24th, 1882. At Crib B it was found necessary to drive a cluster of anchor piles above; this was begun on July 5th, the pile driving for the pier being begun on the following day. On the 13th, the crib work around these piles was begun. The harness on Pier II was raised early in July. The easterly Howe truss span was raised on pile false work, and finished July 7th. The central Howe truss was raised on three barges; these barges had been fitted with false work while moored to the shore below the bridge site; on July 16th, they were placed in position, and the central span of Howe truss was completed on the 21st. On the following day the barges were floated around to the westerly span, and this span was finished on the 25th.

The first metal placed on the false work was the chord bars, the first being run out on the 26th of July; the chord was connected through on the 28th; the traveler was placed at the center of the span, and on the 29th the two center posts, the two posts east of these, and two sections of top chord were raised. The traveler was then worked eastward till the easterly half of the truss was erected, then moved back to the center, and the westerly half was erected. The connections were all completed by the 12th of August, and the span was swung off at 3.30 p. m. on that day.* The truss was swung by placing four small jacks under each vertical post (104 jacks in all), manning all the jacks, and having them turned in unison by a signal given with a whistle; the heavy truss was swung off very easily in about half an hour of actual work. The trusses were so designed that no field riveting was required before swinging, and when swung all the connections of the main trusses and top lateral system were complete. The first floor beams and track swingers were run out and placed on the 13th, and on the 15th, the entire floor was together. The timber floor was begun on the 19th, and on the 21st the permanent track had been laid (though not fully spiked) across the span. The two westerly Howe truss spans had been floated out on the 18th and 21st, and on the 25th Crib B was blown out with dynamite, and a passage for steamboats afforded under the span already erected.

Pile driving for Crib C, under the central main span, was begun on the 25th of July. On the 7th of August the current became very strong at

the site of this crib, and it required very active work for several days to maintain the temporary pier from destruction; the crib was, however, sunk into position and rendered secure with sand-bags and stone. The harness on Pier III was begun on the 19th. The pile driving for Crib D was begun August 11th. On the 18th of August the Howe truss, which had been used under the center of the easterly span, was floated around on the barges which had been used for its erection and placed between Pier II and Crib C, under the central span. On the 21st, the Howe truss, which had been between Crib B and Pier II, was floated around to the space between Crib C and D. The barges were then placed between Crib D and Pier III, and a fourth Howe truss was erected on them, this truss being completed on the 27th. The first chord bars were run out on false work on the 29th; the first post was raised on the 30th, and the truss was swung off in the same manner as the preceding one at 4.15 p. m., September 9th, four weeks after the swinging of the first span. The floor beams were placed on the 12th and 14th; the timber floor was begun on the 17th and finished on the 19th.

Pile driving for Crib E was begun on the 17th of August. The false work between this crib and Pier IV had been begun some time previously. The Howe truss between Pier III and Crib E was erected on pile false work; the truss that had been used next to Pier I was taken down and erected in this position, being completed September 17th. The first chord bars were run out September 25th, and the first posts erected on the following day. The last coupling was made October 6th, and the span swung off at 3.30 p. m. October 7th, exactly eight weeks from the swinging of the first span. The floor beams were placed on the 8th and 9th, and the ties had been laid by the 11th. The riveting of the floor connections was done first; that of the joints in the top chord and the portals followed. The riveting at first proceeded very slowly, owing largely to the lack of competent riveters; it was, however, all completed, excepting some of the portal work, before the 18th. The entire superstructure was raised under the direction of Mr. John W. Stoughton, superintendent of erection for the Detroit Bridge & Iron Works.

FLOOR

The floor on the superstructure consists of oak ties 9 inches square and 15 feet long. They are spaced about 15 inches between centers, or 20 to a panel. On the through spans these ties rest on iron stringers, which are 9 feet between centers; on the deck spans they rest on the top chords,

which are also 9 feet between centers. The track is laid with a 56 pound steel rail of the pattern in common use on the Northern Pacific Railroad. Inside of the rails are placed two lines of angle iron 5 by 4 by $\frac{1}{2}$ inches, laid to an outside gauge of 3 feet 8 inches, with the broad side down, and bolted to every tie with a 1-inch bolt; these angle irons act as guard rails in case of derailment, being placed far enough from the rails to allow a wheel to roll between them; they hold the ties at proper distances apart, and they distribute the excessive weight of a pair of overloaded driving wheels upon several ties. This arrangement makes an elastic floor which can deflect slightly under the passage of a train, thus relieving the iron work from the force of impact, and it distributes the weight thrown by the wheels on a single point of the rail over several feet of iron stringer. At the ends of the ties are placed pine ribbons 8 inches square, sized down 1 inch over every tie, and bolted to every fourth tie; at intervals of about 25 feet are placed light wrought iron stanchions, carrying a $\frac{1}{2}$ inch wire rope, which forms a simple hand-rail for the security of the watchmen in bad weather. This timber floor, including rails and guard angles, is estimated to weigh 450 pounds per lineal foot. At each end of the bridge the guard angles terminate in a point formed of 4 inch oak plank, plated on the outside with iron, these points being designed to direct a derailed wheel into the space between the guard angles and the rail.

TEST

The first train taken across the Bismarck Bridge left Bismarck at 4 p. m., October 18th, 1882. It consisted of 25 empty stock cars, drawn by locomotive No. 88, which was handled by C. W. Rossiter. On the 21st of October, the bridge was formally tested in the presence of a committee of engineers. The test load consisted of eight Mogul locomotives, whose aggregate weight was 1,077,400 pounds, of which 1,050,000 pounds were carried on a single span. The deflections of the six trusses were carefully observed, and are shown on Plate 25. The official report of the engineers who observed this test is given in Appendix M.

The false works above the water were removed in October and November; but so great a deposit had formed around Crib C and D that it was impossible to remove them; the remains of these piers, however, were swept out by the ice floods of the spring of 1883. In the spring of 1883 the superstructure was painted with two heavy coats of Cleveland Iron Clad Paint (purple brand), put on with boiled linseed oil.

* A daily photographic record was kept of the erection of this span.

VII APPROACHES

The east approach to the Bismarck Bridge departs from the old main track of the Northern Pacific Railroad at the west end of the Bismarck yard, opposite Camp Hancock. From the point of connection it curves to the north with a 1° curve (5,730 feet radius) for a distance of 3,152.5 feet, and then runs on a straight line in a north westerly course, 5,597.5 feet; it then curves to the north on an 8° curve (716 feet radius) for a distance of 649 feet; then follows a tangent 213.2 feet long, from which it curves to the west on a 12° curve (478 feet radius) for a distance of 866.7 feet, connecting with the tangent which runs across the bridge on the approach span 75 feet east of the center of Pier I.

The lowest point on this approach is near the east end, the elevation of the bottom of the tie here being 1660. From this elevation the approach ascends with a .5 per cent. grade (26.4 feet per mile) to a summit a little east of the east end of the 8° curve, from which it runs level for 250 feet, and then descends with a .25 per cent. grade (13.2 feet per mile) to the east abutment.

The approach crosses two drainage valleys with temporary timber structures, and a ravine a little east of the 8° curve, where the drainage is provided for by an 18-inch cast iron pipe well bedded in masonry at the ends, and with joints secured by small masonry walls. There are no special features on this approach, except the sharp curves and the deep cuts near the east end of the bridge. The greater part of the 8° curve is through a sand cut, which was so dry that the work had to be abandoned at times on account of dust; this cut was taken out with a 20-foot base, with slopes $1\frac{1}{2}$ to 1. The 12° curve is in a deep clay cut, the clay being the same hard material that is found at the bottom of the river; the excavation of this cut was as hard work as is ever found in material which is properly classified as earth; this cut has a maximum depth of 66.9 feet on the bluff side; it was taken out with a 27-foot base, the track being placed 15 feet from the foot of the higher slope, and the sides were given a slope of 2 horizontal to 3 vertical. The line was purposely located so as to make a short fill between these two cuts, for convenience in construction and also in maintenance, it being considered that this might be of great assistance in case of snow; this location moreover gives trains approaching the bridge from the east a full view of the structure before reaching it. Quite a large portion of the material from both these cuts had to be wasted, and the

greater part of that from the clay cut was wasted between the slope of the bluff and the river, in such a position as to form the level material yard already referred to. The material track already mentioned was laid from the opening between the two cuts along the face of the bluff, and through this yard beyond the end of the bridge; it was also connected temporarily with the track on the bridge, but this required curvature too sharp for general use.

The total amount of material handled on the east approach was 138,107 cubic yards, of which 25,903 yards were taken from the sand cut, and 81,547 yards from the clay cut.

The east approach was graded in 1881, excepting the clay cut, which was not finished till 1882. The track was laid from Bismarck to the material yard in October and November, 1881.

The tangent on the bridge is continued 541.5 feet westerly from the center of Pier IV, from which point the approach curves to the north with a $1^\circ 10'$ curve (4,911 feet radius) for a distance of 4,834.3 feet, where it connects with the tangent of the old track across the bottom land.

From a point 413.5 feet west of the center of Pier IV, the west approach descends with a 1 per cent. grade (52.8 feet per mile) from the elevation 1590 (that of the track on the bridge) to 1534, the elevation of the track across the bottom land; the connection between this grade and the level track at the east end is rounded off with a vertical curve.

From the iron bent at the west end of the approach span to the old shore line, a distance of 1,500 feet, the west approach consists of a timber trestle. This trestle is built in 20-foot spans, and is framed with packed posts, each consisting of two pieces of 6 by 12's, bolted together, with splices for the joints and without mortise or tenon. The trestle is built of pine with a foundation of oak piles; the stringers are covered with sheet iron oiled and painted. The floor consists of 6 by 8-inch oak ties, 12 feet long, laid 16 inches between centers, with refuges every 60 feet, alternating on the two sides. As a protection against fire, the entire trestle was white-washed, and a foot-walk placed inside, about 20 feet below grade, for the convenience of the watchmen.

An earth embankment was built along the up-stream side of this trestle, the center line being placed 60 feet from the center of the trestle; this embankment finishes at an elevation of 1650, and is intended to shield the trestle from the action of ice. It is so located that it will come almost entirely within the limits of a permanent embankment whenever the trestle is filled. This embankment is built with material brought in on cars partly

from the borrow pit in the bluff near Mandan, and partly from a borrow pit three miles west of Mandan; a small portion of the lower part of the bank was scraped in from the side.

The timber for the trestle was delivered in the winter of 1881-2, on the east approach, where it was framed; it was transferred in April, 1882, and the piles were driven and the trestle raised in the spring and early summer, the last bent being erected on the 24th of June.

Beyond the timber trestle, the west approach consists of an earth embankment containing 213,760 cubic yards, of which 149,260 yards were scraped from borrow pits at the sides, and the balance was brought from the borrow pit near Mandan, the cars being dumped from a temporary cottonwood trestle furnished by the contractors. Work on this embankment was begun in the fall of 1881, and was completed so that trains could run over it on to the trestle early in September, 1882. The embankment settled considerably as it was built and afterwards; it is still in places somewhat below grade.

The total amount of material handled in the west approach was 308,480 cubic yards, of which 213,760 yards were in the embankment west of the trestle, and 94,720 yards in the protection embankment and the fill between Pier IV and the Cushing pier. Of the whole amount, 170,453 cubic yards were borrowed from the bottom land and sand bar, 120,782 cubic yards were brought from the contractors' borrow pit near Mandan, and 17,245 cubic yards from the company's borrow pit.

The contractors' borrow pit near Mandan consisted of hard clay, similar to that found in the east bluff and in the bottom of the river; it was worked successfully with a Wilcox & Stock steam shovel, but was as hard a material as could be worked in this way.

The reasons for not raising the track across the bottom land beyond the approach have been given in an earlier part of this report. The importance of leaving this low ground as a safety-valve in case of ice gorges must always be remembered. If it is thought expedient to raise it, it should either be done on a light structure, which the ice will destroy if it runs heavily, or on a more permanent structure, which will allow the ice to pass through it; a solid embankment across this bottom land ought never to be built.

THE BISMARCK BRIDGE

19

VIII COST

The circumstances under which the Bismarck Bridge was built were not favorable to cheap construction. At that time Bismarck was practically 150 miles from any settled country, and the nearest labor market was St. Paul, 470 miles distant. At the same time, the construction of the Northern Pacific Railroad was being vigorously prosecuted farther west, and the demand for labor very largely exceeded the supply. The general price paid for ordinary laborers was \$2.00 per day, and the wages of mechanics were proportionately higher. This however was not the worst feature, as the labor in this country was of an inferior character, and very difficult to control, the

men generally being indifferent as to whether they worked or not, and entirely ready to be discharged. It frequently happened that gangs of men sent out from St. Paul to work on the bridge disappeared almost as soon as they arrived.

The cost of the bridge is shown in the table on the following page. This gives the entire cost of the work from the time it was placed in my charge, in January, 1881, to the time when it was turned over to the operating department, August 1st, 1883. It does not include the work done on the dike and elsewhere prior to January, 1881, and does not include any expenditures for real estate or right of way.

In this statement the charges for freight are exclusively for transportation on the Northern Pacific Railroad, the amounts paid for freight on material before it reached the Northern Pacific Railroad being included in the first column. In comparing the cost of this bridge with other structures, the

cost exclusive of freight on the Northern Pacific Railroad is the most correct measure to go by.

The report made in July, 1880, estimated the cost of this bridge and approaches at \$700,000, exclusive of freight on the Northern Pacific Railroad. In this report the cost of the bridge proper, not including freight, was estimated at \$500,000, to which an addition of \$25,000 was made in December, 1880, making \$525,000; the increase of cost has therefore been almost entirely in the approaches and protection work. A small portion of this increase is accounted for by the fact that only 1,500 feet of trestle-work were used in the west approach, instead of 3,000 feet, as originally contemplated. But the principal increase is due to the great change in the value of labor and materials between the summer of 1880 and the time when the work was executed, this increase being more than one-third, and about corresponding to the actual increase in the cost of the work.

THE BISMARCK BRIDGE

COST, EXCLUSIVE OF FREIGHT CHARGES				FREIGHT CHARGES		TOTAL COST, INCLUDING FREIGHT CHARGES	
East Abutment	\$1,024 75			\$614 59		\$1,039 37	
Pier I. Foundation.....	\$2,555 85			\$452 78		\$3,008 63	
Concrete.....	8,980 33			1,616 54		10,596 87	
Masonry.....	10,098 84			14,199 46		24,298 30	
Riprap.....	6,330 76			940 39		7,271 15	
	36,443 75			17,239 17		53,682 92	
Pier II Foundation.....	\$40,452 80			\$7,429 30		\$47,882 10	
Concrete.....	14,448 09			2,952 13		17,400 22	
Masonry.....	54,625 80			40,220 44		94,846 24	
Riprap.....	9,498 67			1,495 81		10,994 48	
	119,025 36			52,097 77		171,123 13	
Pier III Foundation.....	\$37,549 50			\$5,153 15		\$42,702 65	
Concrete.....	13,850 33			3,088 72		16,939 05	
Masonry.....	51,471 45			39,769 5		91,240 50	
	105,871 28			48,011 87		153,883 15	
Pier IV. Foundation.....	\$8,646 60			\$3,340 47		\$11,987 07	
Concrete.....	2,458 56			73 13		2,531 69	
Masonry.....	21,810 51			16,814 87		38,625 38	
Riprap.....	10,017 30			1,494 17		11,511 47	
	42,933 97			22,433 00		65,366 97	
Cushing Pier.....	1,394 86			274 70		1,669 56	
TOTAL SUBSTRUCTURE.....	\$177,137 54			\$142,621 71		\$319,759 25	
Three 400-foot Spans.....	\$108,083 29			\$10,332 59		\$118,415 88	
Two 113-foot Spans.....	10,475 40			688 58		11,164 98	
Iron Bent.....	739 40			47 71		787 11	
	\$119,298 09			\$11,068 88		\$130,366 97	
Erection.....	12,530 00			14,158 53		26,688 53	
Floor.....	9,816 37			3,013 35		12,829 72	
Painting.....	1,536 92			70 01		1,606 93	
Sundries.....	375 90			6 57		382 47	
TOTAL SUPERSTRUCTURE.....	\$143,567 68			\$28,317 34		\$171,885 02	
TOTAL BRIDGE PROPERTIES.....	\$320,705 22			\$171,039 05		\$491,744 27	
Protection of East Shore.....	\$8,560 87			\$1,394 33		\$9,955 20	
Dike and Accesses.....	78,203 22			15,977 37		94,180 59	
	\$86,764 09			17,371 70		\$104,135 79	
East Approach.....	\$37,843 05			\$3,354 63		\$41,197 68	
West Approach.....	126,786 97			25,332 16		152,119 13	
Permanent Track.....	21,053 49			4,025 96		25,079 45	
	186,683 51			33,713 05		220,396 56	
Engineering and Inspection.....	\$35,543 59			\$487 42		\$36,031 01	
Office Expenses.....	622 2			201 32		823 54	
Building and Tools.....	3,912 97			791 33		4,704 30	
TOTAL.....	\$235,060 01			\$148,007 07		\$383,067 08	

APPENDIX A

LIST OF ENGINEERS, EMPLOYES AND CONTRACTORS

ENGINEERS AND COMPANY'S EMPLOYEES

NAME AND OCCUPATION	TIME OF SERVICE
Geo. S. Morrison, Engineer and Superintendent	
H. W. Parkhurst, First Assistant Engineer	Jan. 1, 1881 to June 12, 1882.
B. L. Crosby, Assistant Engineer	April 6, " " Aug. 1, 1883
Geo. A. Lederle, Assistant Engineer and Draughtsman	July 16, " " Nov. 1, 1882.
David R. Alden, Leveler	Feb. 5, " " Sept. 1, 1881.
C. C. Schneider, Assistant Engineer of Superstructure	Jan. 1, " Oct. 31, 1882
W. F. Zimmermann, Inspector of Steel and Iron	Mar. 3, " " Aug. 8, "
James S. Sanderson, Inspector of Shop Work	May 1, " " Aug. 30, "
Robert Ross, Inspector of Masonry	July 13, " " June 5, "
B. S. Sawyer, Inspector at Quarries	June 11, " " Apr. 30
F. S. Sylvester, Inspector of Transportation	Oct. 26, " " Sept. 11
John A. McKee, Foreman in charge of Borings, &c	Feb. 10, " " Dec. 6, 1881.
John McGee, Foreman of Laborers	Jan. 1, " " Apr. 11, "
R. P. Slitt, " " "	Feb. 22, " " July 1, 1883.
Wm. L. Bechtel, Foreman of Superstructure	Nov. 21, 1881, " Aug. 1, "

CONTRACTORS

NAME	NATURE OF WORK
Saulpaugh & Company	Substructure.
J. Crubaugh, Resident Partner and Superintendent.	
Patrick Durack, Foreman of Masons.	
Oliver Davis, Foreman of Stone Cutters.	
Russ & Coolidge, Subcontractors for Pneumatic Work.	
Detroit Bridge & Iron Works	Superstructure.
John W. Stoughton, Superintendent of Erection.	
Bellows, Fogarty & Company.	Earthwork on Approaches
Winston Brothers	Trestle-work, West Approach.
Charles W. Thompson	Riprap Stone.

APPENDIX B

SPECIFICATIONS FOR SUBSTRUCTURE

The substructure will be understood to include the masonry and foundations of the bridge proper.

There will be four piers, numbered from the east to the west, the east pier being No. I, and the west No. IV.

PIER I

Pier I will stand back of the shore line on the east side.

An open pit about 50 feet long and 20 feet wide shall be excavated to such depth as may be necessary to reach a bottom of solid rock, or of such material as may be satisfactory to the Engineer. This excavation shall be filled with concrete to an elevation not lower than three feet below low water.

The masonry shall be started on the surface of the concrete, and the pit shall be filled with earth and rammed around the masonry to the elevation of the natural surface of the ground.

PIERS II AND III

Piers II and III will be in the channel of the river.

Each of these piers shall be founded on a pneumatic caisson, which shall be sunk to the underlying bed-rock, and to such depth into the rock as may be determined by the Engineer.

The caissons shall be constructed according to the plans furnished by the Engineer. The frames shall be of pine timber; the outside sheathing shall consist of two thicknesses of three-inch oak plank, the planks of the inside course to be inclined at an angle of 45°; the working chamber shall be lined with three-inch pine plank, jointed and calked, and shall be painted with two heavy coats of Cleveland Iron Clad Paint (purple brand) before sinking. Each course of timber in the sides shall be fastened to the course below with drift bolts not more than three feet apart, these drift bolts to be $\frac{1}{2}$ of an inch square and to reach through two courses of timber and six inches into a third course, being, generally, 30 inches long. The oak sheathing shall be spiked with wrought iron boat-spikes, 7 inches long by $\frac{3}{8}$ of an inch square, at least two spikes to each square foot of each course of planking. The corners of the caisson shall be plated on the outside with boiler-plate, the plates to be 30 inches wide and $\frac{1}{2}$ of an inch thick, bent to a quarter circle and fastened with 7 by $\frac{3}{8}$ -inch wrought iron boat-spikes, at distances not exceeding six inches apart on a line one inch back from each edge. All timber shall be thoroughly sound and strong. The wrought iron used shall be of a tough, fibrous character, as tested by cutting and bending. The workmanship throughout shall be thorough and satisfactory to the Engineer.

The caisson shall be filled above the working chamber with concrete, the surface of which shall always be kept above water. Such opening shall be left in the concrete filling as may be necessary for working and supply shafts.

The caisson shall be sunk by the pneumatic process, the sand being removed by the Eads sand pump, or by such other apparatus as may be approved by the Engineer. Blowing off will not be permitted, but the air pressure shall, at all times be maintained in the caisson, which shall be forced down by the weight of the concrete and masonry above. The contractor will be required to furnish two independent air compressors, each of which shall be of sufficient capacity to provide a full supply of air for the caisson, without assistance from the other.

The position of the caisson will not be allowed to vary more than 18 inches in any direction from the true position of the pier, as located by the Engineer, at any time during the progress of the sinking. The caisson shall not be allowed to vary more than 18 inches from a true level in its length, nor more than six inches in its width, and shall be brought to a true level when the sinking is completed.

When the sinking is completed, a joint shall be made between the cutting edge of the caisson and the bed-rock, either by cutting away the rock or by ramming bags of concrete into

the spaces between the cutting edge and the rock, as may be directed by the Engineer; the sand and mud shall be cleaned from the surface of the rock, and the entire working chamber shall be filled with concrete, special pains being taken to ram the concrete thoroughly against the roof.

The masonry shall be begun when the concrete filling is ready for it, on the level of the top of the caisson, and shall be built with openings for working shafts conforming to those in the concrete. The surface of the masonry shall be kept above water as the sinking progresses. When the filling of the working chamber is completed, the shafts in the concrete and masonry shall be filled with concrete and the masonry shall be finished.

PIER IV

Pier IV will stand on the sand-bar on the west side of the river, south of the dike.

This pier will have a pile foundation.

An excavation shall be made on the site of the pier to a depth about six feet above low water. In this excavation an open caisson or curb shall be built; it shall be 28 feet wide, 55 feet long and 12 feet high, built of 12 by 12-inch pine timber, the sides being pinned together with oak trenails and planked on the outside with one course of three-inch oak plank; it shall be sunk by excavating inside till the lower edge is six feet below low water. In this curb 160 piles shall be driven; the piles shall be of oak, not less than 10 inches in diameter at the small end, nor less than 16 inches at the large end; they shall be driven with a hammer weighing not less than 3,500 lbs. The average penetration below the bottom of the curb shall not be less than 28 feet, and no pile shall be driven less than 25 feet. The piles shall be cut off square and level, four feet below low water, and shall be capped with two courses of 12 by 16-inch oak timber, the lower course being fastened to each pile with a one-inch square drift bolt 30 inches long, and the timbers of the second course fastened to those of the first course with $\frac{3}{4}$ -inch square drift bolts 22 inches long. The space around the piles and between the timbers shall be filled with concrete, on the surface of which the masonry shall be started.

About 1,000 cubic yards of riprap, consisting of field boulders or other suitable stone, shall be piled around this pier, in a manner satisfactory to the Engineer.

CONCRETE

Concrete shall be formed of cement and sand or gravel, in proportions varying from two to four parts of sand or gravel to one of cement, as may be directed by the Engineer, for different parts of the work. It shall be mixed in a machine mixer, of such pattern as may be approved by the Engineer, with as small an amount of water as is consistent with thorough moistening of the mass. It shall be laid under the direction of the Engineer, and when required thoroughly rammed with a 40-pound ram. Rubble-stone of irregular size and shape shall be thrown in with the mass, in as large quantities as is consistent with a complete bonding of the concrete mass around every stone, the stones being handled separately, and bedded in the soft concrete mass. The grouting of quantities of loose stone will not be allowed.

The concrete used to fill the working chamber will be entirely of cement and sand or gravel.

MASONRY

The masonry will be first-class rock-face work, laid in regular courses, to be built of granite from quarries in Minnesota. The piers shall conform in all respects to the plans furnished by the Engineer.

No course shall be less than 16 inches thick, and no course shall be thicker than the course below it. The upper and lower beds of every stone shall be at least one-half greater in both directions than the thickness of the course.

In general, every third stone of each course shall be a header, and there shall be at least two headers on each side of each course between the shoulders. No stone will be considered a header that measures less than five feet back from the face. The headers shall be so arranged

as to form a bond entirely through the pier, either by bonding against a face-stone in the opposite side of the course, or by bonding with a piece of backing not less than three feet square, which shall bond with a face-stone on the opposite side. In all cases the interior bonding shall be further secured by placing in the course above a stone at least three feet square over the interior joints. Special care shall be taken with the bonding of the ice-breaker cut-water, the stones of which shall be so arranged that the face-stones are supported from behind by large pieces of backing.

All joints shall be pitched to a true line and dressed to one-quarter of an inch for at least 12 inches from the face. Beds, both upper and lower, shall be pitched to a true line and dressed to one-quarter of an inch. Joints shall be broken at least 15 inches on the face.

The ice breaker starting of Piers II and III shall have a smooth, bush-hammered face. There shall be a draft line three inches wide around the lower edge of the belting course below the coping. The coping over the whole pier shall have a smooth, bush-hammered surface and face. All other parts of the work shall have a rough quarry face, with no projection exceeding two inches from the pitch lines of the joints.

The stones in the coping under the bearings of the trusses shall be at least four feet wide, and shall reach back six feet from the face. They shall have good beds for their entire size, and shall have a full bearing on large stones with dressed beds in the belting course below the coping.

The large stones used in the backing to bond with the headers, and to support the ice-breaker face stones as above described, shall be of the same thickness as the face-stones and shall have dressed beds. The remainder of the backing shall be formed of good rubble-stone, thoroughly bedded in mortar.

All stones shall be sound, free from seams or other defects.

All stones shall be laid in full mortar beds; they shall be lowered on the bed of mortar, and brought to a bearing with a maul. No spalls will be allowed, except in small vertical openings in the backing. Thin mortar joints will not be insisted on, but the joints shall be properly cleaned on the face and pointed in mild weather.

The face-stones of each course in Piers II and III for a height of 30 feet, beginning about three feet below low water, shall be doweled into those of the course below, with round dowels of 1 1/2-inch iron extending six inches into each course; the dowels shall be from eight to twelve inches back from the face, and six inches on each side of every joint; the stones of the upper course shall be drilled through before setting, after which the drill-hole shall be extended six inches into the lower course; a small quantity of mortar shall then be put in the hole, the dowel dropped in and driven home, and the hole filled with mortar and rammed.

The mortar will be composed of cement and clean, coarse sand, satisfactory to the Engineer, in proportions varying from one to three parts of sand to one of cement, as may be directed by the Engineer for different parts of the work. When stone is laid in freezing weather, the contractor shall take such precautions to prevent the mortar freezing as shall be satisfactory to the Engineer.

TERMS

The Railroad Company will furnish free transportation for the contractor's tools and men on the lines of the Northern Pacific Railroad, and free transportation of stone from the quarries to the bridge site.

The Railroad Company will furnish the cement for the masonry, which must be unloaded and stored by the contractor, he to be responsible for it afterwards.

The contractor will be required to furnish all boats, barges, derricks and tools of every description, both at the quarries and on the works. The stone shall be cut at the quarries. The Railroad Company will furnish no tools nor material except cement.

No material shall be measured or included in the estimate, which does not form a part of the permanent structure.

APPENDIX C

RECORD OF TESTS OF CLAY

COMPRESSION TESTS

Date	Location taken from	Cy- Stems	Length	Remarks
1881				
September 8	South Section, P. 1	65		Clay of bluish color, with considerable sand intermixed with it. Samples from elevation 1660. Tests
" "	" "	55		" "
" "	" "	50		" "
" "	" "	47		" "
" "	" "	43		" "
" "	" "	38		" "
" "	" "	35		" "
" "	" "	32		" "
November 18	" "	25		" "
" "	" "	20		" "
" "	" "	18		" "
" "	" "	130		" "
October 25	Per H Elev. 1573 1	143		Dark brown clay.
" "	" "	130		" "
" "	" "	122		" "
" "	" "	100		" "
" "	" "	12		Dark-blue clay, north end.
" "	" "	11		" "
" "	" "	10		" "
November 12	" "	1568		Bluish clay, south end.
" "	" "	19		" "
" "	" "	231		Brown clay, north end
1882				
January 12	Per H " 1569	12		Northerly 60 feet of foundation of same character, bluish-gray clay, with sandy spots, quite small, scattered throughout it.
" "	" "	45		" "
" "	" "	117		" "
" "	" "	132		" "
" "	" "	137		Southerly 20 feet of foundation.
" "	" "	225		Brown clay, with lignite.

TENSILE TESTS

Date	Location taken from	Section of Specimen	Breaking Strain Lbs.	Remarks
1881.				
September 8	Pier I.	a square inch.	7	Sample from elevation 1600
" 25	"	"	"	"
" 25	"	"	15	" "
October 24	Pier II	"	324	" " 1573.
" 31	"	"	32	" "

TESTS MADE WITH LEVER APPARATUS ON CLAY IN FOUNDATIONS
ON NATURAL SURFACE

Location	Bearing	SPIN ITS	Depression	Remarks
Pier I.	2° by 2°	500.	3/8" in 10 m	Bearing not uniform.
"	1 1/2 by 1 1/2"	"	1/2" 10 "	"
"	1° by 1°	"	" 10 "	Soft spot
"	"	"	1 1/2" 10 "	Lever slipped.
"	1 1/2 1 1/2 "	"	" 10 "	"
Pier II, N. E. corner in trench	"	380	3/8" 10 "	Dry spot.
" N. end in trench	"	475	3/8" 10 "	Bluish clay.
" S. " in center	"	342	3/8" 10 "	Black "
" "	"	58	3/8" 10 "	lite "
See III " N. E. corner in trench.	"	300	3/8" 10 "	Dark-brown clay.
" West side on lignite	"	800	3/8" 10 "	Scarcely visible mark
" East side, sandy clay	"	540	3/8" 10 "	"
" N. end, W. side, at first beam	"	23	3/8" 10 "	"
" "	"	750	3/8" 10 "	"

APPENDIX D

LIST OF BORINGS AND TEST PITS

Boring No. 1, made February 14th-18th, 1881, 150 feet south of Station 4 + 87.	
Top of sand.....	1619.7
Through fine sand 22 feet to coal at.....	1597.7
" coal .3 feet to coarse sand at.....	1597.4
" coarse sand and pebbles 15.4 feet to.....	1582.
Water rose and drove men away, so that sounding could not be completed.	
Boring No. 2, made March 3d-7th, 1881, Station 4 + 87.	
Top of sand.....	1617.
Through fine sand 33.8 feet to coal at.....	1583.2
" coal .7 feet to sand at.....	1582.5
" sand 4.65 feet to bluish clay at.....	1577.85
" bluish clay 17.85 feet to softer clay at.....	1560.
" softer clay 1 foot to bluish clay at.....	1559.
" bluish clay 7.3 feet to rock at.....	1551.7
Into rock .8 feet to.....	1550.9
Test Pit No. 1, made January 10th to March 7th, 1881, 150 feet south of Station 0 + 85.	
Top of ground.....	1637.2
Through frost 3.5 feet to sandy clay at.....	1633.7
" sandy clay 16 feet to silt at.....	1617.7
" silt 3 feet to blue clay at.....	1614.7
" blue clay 5.5 feet to clay and sand stratified at.....	1609.2
" clay and sand stratified 9 feet to.....	1600.2
At this depth the pit was declared unsafe, and the boring machine was set up and a 2 1/2" pipe driven down to.....	
Then a 2" drill and the sand pump were run to.....	1592.5
	1583.2
Test Pit No. 2, made February 1st to March 10th, 1881, Station 0 + 85.	
Top of ground.....	1639.4
Through clayey sand 18 feet to.....	1621.4
" clayey sand and pieces of sandstone 4.5 feet to compact clay and sand at.....	1616.0
" compact clay and sand 2 feet to large piece of sandstone at.....	1614.9
" large piece of sandstone 1 foot to clay and sand at.....	1613.9
" clay and sand 3.3 feet to sand (with water) at.....	1610.6
" sand (with water) 3 feet to brittle clay at.....	1607.6
" brittle clay 2.4 feet to coal at.....	1605.2
" coal .3 feet to tough clay at.....	1604.9
" tough clay 9.5 feet to coal at.....	1595.4
" coal 2 feet to clay at.....	1593.4
" clay by running down a 1 1/2" drill to.....	1539.7
Boring No. 3, made April 23d-26th, 1882, 13.5 feet south of Station 4 + 85.25.	
Top of sand.....	1617.5
Through sand 42.5 feet to clay at.....	1575.
" clay 22.5 feet to rock at.....	1552.5
" rock 1.1 feet to clay at.....	1551.4
" clay 10.7 feet to rock at.....	1540.7
" rock .35 feet to clay at.....	1540.35
Then drilled into clay 29.5 feet to elevation.....	1510.5
Boring No. 4, made April 26th-28th, 1882, 11.5 feet north of Station 4 + 89.75.	
Top of sand.....	1616.8
Through sand 40.8 feet to blue clay at.....	1576.
" blue clay 23.5 feet to rock at.....	1552.5
" rock 1.25 feet to clay at.....	1551.25
Into clay 8.25 feet to elevation.....	1543.
Boring No. 5, made April 28th-30th, 26.1 feet north of Station 4 + 62.5.	
Top of sand.....	1622.
Through sand 44.6 feet to clay at.....	1577.4
Into clay 17.4 feet to elevation.....	1560.
At this depth, the waves from the transfer steamer broke the pipe, and 48.5 feet of it were lost. This pipe was afterwards recovered when the caisson for Pier 11 was sunk.	
Boring No. 6, made April 30th to May 4th, 35.2 feet north of Station 5 + 59.5.	
Top of sand.....	1621.5
Through sand 33.8 feet to blue clay at.....	1587.7
" blue clay 35.2 feet to rock at.....	1582.2
" rock 2.2 feet to clay at.....	1567.2
Into clay 1.3 feet to.....	1549.
Boring No. 7, made May 4th-6th, 44.7 feet north of Station 5 + 09.6.	
Top of sand.....	1610.7
Through sand 41.8 feet to sandstone at.....	1577.9
" sandstone 1.1 feet to blue clay at.....	1576.8
Into blue clay 36.2 feet to.....	1540.6
Boring No. 8, made May 7th-9th, 53.3 feet north of Station 4 + 79.15.	
Through sand to coarse pebbles at.....	1585.
" coarse pebbles 1 foot to fine sand at.....	1584.
" fine sand with a little coal to a log at.....	1583.
" log 1 foot to sand at.....	1582.
" sand 13.7 feet to clay at.....	1568.3
" clay 15.1 feet to rock at.....	1553.2
" rock .35 feet to clay at.....	1552.85
Into clay 7.15 feet to.....	1545.7
Boring No. 9, made August 16th-24th, Station 13 + 00.	
Top of sand.....	1624.8
Through fine sand mixed with coal and pebbles 59 feet to coal at.....	1565.8
" coal mixed in lower part of strata with lumps of clay and sand 3 feet to coarse sand at.....	1562.8
" coarse sand 3 feet to fine sand at.....	1559.8
" fine sand mixed with some coal 18.8 feet to blue clay at.....	1541.
Into blue clay 10.8 feet to.....	1530.2
Boring No. 10, August 24th to September 12th, Station 12 + 86.5.	
Top of sand.....	1624.8
Through fine sand 30 feet to coarse sand, etc., at.....	1594.8
" coarse sand with large pebbles and coal 35 feet to very fine sand at.....	1559.8
" very fine sand 15 feet to coal at.....	1544.8
" coal .1 feet to blue clay at.....	1544.7
Into blue clay 10.3 feet to.....	1534.4
Boring No. 11, made August 24th to September 12th, Station 12 + 73.	
Top of sand.....	1624.8
Through fine sand 30 feet to coarse sand, coal, etc., at.....	1594.8
" coal, coarse sand and pebbles, with a little yellow clay at bottom, 28 feet to coarse sand at.....	1566.8
" coarse sand and pebbles 23 feet to blue clay at.....	1543.8
Into blue clay 3.4 feet to.....	1540.4
Boring No. 12, made September 13th-22d, Station 10 + 97.5.	
Top of sand.....	1625.
Through fine sand 28 feet to coarse sand and coal at.....	1597.
Through coarse sand and coal 14 feet to coal.....	
" coal 1 foot to coarse sand and pebbles at.....	1585.
" coarse sand and pebbles 7.4 feet to dark clay at.....	1574.6
" dark clay 1 foot to coarse pebbles at.....	1573.6
" coarse pebbles 15.2 feet to fine dark sand at.....	1558.4
" fine dark sand 3.1 feet to blue clay at.....	1553.3
Into blue clay 15.9 feet to.....	1539.4
Boring No. 13, made September 23d to October 3d, 20 feet south of Station 10 + 97.5.	
Top of sand.....	1625.
Through fine sand 28 feet to gravel at.....	1597.
" gravel 2 feet to fine sand at.....	1595.
" fine sand with a little coal 19 feet to coal, etc., at.....	1576.
" coal and small balls of clay .8 feet to coarse sand, etc., at.....	1575.2
" coarse sand, gravel and coal 10.2 feet to fine black sand at.....	1565.
" fine black sand .2 feet to coarse gravel, etc., at.....	1564.8
" coarse gravel and fine sand 9.2 feet to blue clay at.....	1555.6
Into blue clay and a few pieces of sandstone to.....	1540.2
Boring No. 14, made October 4th-6th, 43 feet north of Station 8 + 74.35.	
Top of sand.....	1606.5
Through sand and gravel 25.1 feet to black sand at.....	1581.4
" black sand .1 feet to sand and gravel at.....	1581.3
" sand and gravel 6.2 feet to blue clay at.....	1575.1
Into blue clay 16.9 feet to.....	1558.2
Boring No. 15, made October 7th-11th, 40.3 feet north of Station 8 + 93.85.	
Top of sand.....	1606.5
Through sand and gravel with a little coal 31.3 feet to black clay at.....	1575.2
" black clay .1 feet to blue clay at.....	1575.1
Into blue clay 15.2 feet to.....	1559.9
Boring No. 16, made October 12th-13th, 25 feet north of Station 8 + 75.	
Top of sand.....	1606.5
Through sand, coal and pebbles 31 feet to dark clay at.....	1575.5
" dark clay .1 feet to blue clay at.....	1575.4
Into blue clay 15.1 feet to.....	1560.3
Boring No. 17, made October 14th-18th, 18 feet south of Station 8 + 75.5.	
Top of sand.....	1607.5
Through sand, gravel and coal 29.2 feet to blue clay at.....	1578.3
Into blue clay 14.1 feet to.....	1564.2
Boring No. 18, made October 18th-20th, 20.75 feet south of Station 9 + 07.	
Top of sand.....	1608.1
Through sand, gravel and coal 29.3 feet to blue clay at.....	1578.8
Into blue clay 5.3 feet to.....	1573.5
Boring No. 19, made November 26th-30th, 74.8 feet north of Station 8 + 70.25.	
Top of sand.....	1610.7
Through fine sand and gravel 17.6 feet to coal at.....	1593.1
" coal .9 feet to sand and gravel at.....	1592.2
" sand and gravel 4.1 feet to fine black sand at.....	1588.1
" fine black sand 3 feet to gravel at.....	1585.1
" gravel 5 feet to black sand and gravel at.....	1580.1
" black sand and gravel 4.5 feet to clay at.....	1575.6
Into clay 4.7 feet to.....	1570.9

APPENDIX D—CONTINUED

Boring No. 20, made December 24-5th, 61.8 feet north of Station 9 + 16		
Top of sand.....	1607.1	
Through coarse sand and gravel with a little coal 17.1 feet to fine sand at.....	1590.05	
" fine sand 5 feet to coarse sand and gravel at.....	1585.0	
" coarse sand and gravel 6 feet to fine sand at.....	1579.0	
" fine sand 4.8 feet to clay at.....	1574.2	
Into clay 4 feet to.....	1570.2	
Boring No. 21, made November 7th-8th, Station 4 + 28.25.		
Top of sand.....	1623.7	
Through fine sand 47.4 feet to clear gravel at.....	1576.3	
Into clear gravel 2.2 feet to hard boulder at.....	1574.1	
(Could not get through this boulder, so hole was abandoned.)		
Boring No. 22, made November 3d-5th, 74.3 feet north of Station 4 + 40.25.		
Top of sand.....	1622.8	
Through fine sand and a few small stones 51.8 feet to blue clay at.....	1571.0	
" blue clay .5 feet to coarse gravel at.....	1570.5	
" coarse gravel .9 feet to hard blue clay at.....	1569.6	
Into hard blue clay 5 feet to.....	1564.6	
Boring No. 23, made November 5th-7th, 75 feet north of Station 4 + 65.		
Top of sand.....	1622.2	
Through fine sand with a few pebbles 40 feet to coarse gravel at.....	1582.2	
" coarse gravel with a little coal 10 feet to blue clay at.....	1572.2	
" blue clay .2 feet to fine sand at.....	1572.0	
" fine sand 5.6 feet to dark clay at.....	1566.4	
Into dark clay, which turned into blue clay after a slight depth, 4.1 feet to.....	1562.3	
Boring No. 24, made November 9th 11th, 50 feet north of Station 4 + 40.		
Top of sand.....	1623.1	
Through fine sand 33 feet to coarse sand and gravel at.....	1590.1	
" coarse sand and gravel 11 feet to fine black sand at.....	1579.1	
" fine black sand .5 feet to coarse sand and gravel at.....	1578.6	
" coarse sand and gravel 10 feet to clay at.....	1568.6	
Into clay 3.9 feet to.....	1564.7	
Boring No. 25, made November 12th-26th, Station 4 + 53.		
Top of sand.....	1622.0	
Through sand and pebbles 53.3 feet to clay at.....	1570.7	
Into clay 4.2 feet to.....	1566.5	
Boring No. 26, made November 12th 26th, Station 4 + 28.		
Top of sand.....	1623.75	
Through fine sand and pebbles 50.2 feet to clay at.....	1573.55	
Into clay 4.4 feet to.....	1569.15	
Boring No. 27, made November 12th-26th, Station 3 + 74.		
Top of sand.....	1623.0	
Through sand 33 feet to coal at.....	1590.0	
" coal 1 foot to sandstone at.....	1589.0	
" sandstone 1.4 feet to fine black sand at.....	1587.6	
" fine black sand 4.5 feet to clay at.....	1583.1	
Into clay 5 feet to.....	1578.1	
Boring No. 28, made November 12th-26th, Station 3 + 28.		
Top of sand.....	1622.4	
Through fine sand 26 feet to sandstone at.....	1596.4	
" sandstone .9 feet to black sand at.....	1595.5	
" black sand .5 feet to clay at.....	1595.0	
Into clay 4 feet to.....	1591.0	
Boring No. 29, made November 12th-26th, Station 2 + 78.		
Top of sand.....	1621.95	
Through fine sand 22.9 feet to clay at.....	1599.05	
Into clay 4.5 feet to.....	1594.55	
Boring No. 30, made November 12th 26th, Station 2 + 28.		
Top of sand.....	1620.8	
Through fine sand 19.6 feet to clay at.....	1601.2	
Into clay 4.5 feet to.....	1596.7	
Boring No. 31, made November 12th-26th, Station 1 + 78.		
Top of sand.....	1620.5	
Through fine sand 18.7 feet to clay at.....	1601.8	
Into clay 5 feet to.....	1596.8	
Boring No. 32, made December 27th 28th, Station 5 + 28.		
Top of sand.....	1619.8	
Through fine sand with some coal and gravel 35.2 feet to coarse sand at.....	1584.6	
" coarse sand and gravel 2 feet to clay at.....	1582.6	
Into clay 5 feet to.....	1577.6	
Boring No. 33, made December 30th, 1881, to January 2d, 1882, Station 5 + 78.		
Top of sand.....	1616.7	
Through fine sand with some coal 27 feet to coarse sand, etc., at.....	1589.7	
" coarse sand and gravel 7.5 feet to small boulder at.....	1582.2	
(At this depth a stone became fixed in end of pipe, so that boring had to be abandoned.)		
Boring No. 34, made January 2d 4th, Station 5 + 88.		
Top of sand.....	1616.5	
Through fine sand 22.5 feet to coal at.....	1594.0	
" fine sand and coal 7 feet to coarse sand at.....	1587.0	
" coarse sand and gravel 4 feet to gravel at.....	1583.0	
" gravel 2.5 feet to clay at.....	1580.5	
Into clay 5 feet to.....	1575.5	
Boring No. 35, made January 5th-9th, Station 6 + 28.		
Top of sand.....	1615.0	
Through fine sand with a little coal 27 feet to coarse sand at.....	1588.0	
" coarse sand and gravel 6.4 feet to sandstone at.....	1581.6	
" sandstone 1.8 feet to clay at.....	1579.8	
Into clay 3.5 feet to.....	1576.3	
Boring No. 36, made January 9th-11th, Station 6 + 78.		
Top of sand.....	1612.6	
Through fine sand 23.8 feet to coarse sand, etc., at.....	1588.8	
" coarse sand and coal 6 feet to gravel at.....	1582.8	
" gravel 2 feet to coarse sand, etc., at.....	1580.8	
" coarse sand and coal 1.8 feet to blue clay at.....	1579.0	
Into clay 5.4 feet to.....	1573.6	
Boring No. 37, made January 11th-14th, Station 7 + 28.		
Top of sand.....	1612.4	
Through fine sand and a little coal 25.4 feet to coarse sand at.....	1587.0	
" coarse sand and gravel 9.1 feet to blue clay at.....	1577.9	
Boring No. 38, made January 14th 18th, Station 7 + 78.		
Top of sand.....	1609.6	
Through fine sand and coal 22.2 feet to gravel and coal at.....	1587.4	
Through gravel and coal 9.5 feet to blue clay at.....		1577.9
Into clay 5 feet to.....		1572.9
Boring No. 39, made January 23rd-24th, Station 9 + 83.		
Top of sand.....	1607.7	
Through fine sand and coal 23 feet to coarse sand and gravel at.....	1584.7	
" coarse sand and gravel 9.3 feet to fine sand at.....	1575.4	
" fine sand and coal 2 feet to blue clay at.....	1573.4	
Into blue clay 5 feet to.....	1567.9	
Boring No. 40, made January 25th to February 1st, Station 10 + 33.		
Top of sand.....	1607.3	
Through fine sand and coal 24.5 feet to gravel at.....	1582.8	
" gravel 4.2 feet to blue clay at.....	1578.6	
" blue clay .8 feet to fine sand at.....	1577.8	
" fine sand 6 feet to gravel at.....	1571.8	
" gravel and coal 8.5 feet to blue clay at.....	1563.3	
Into blue clay 6 feet to.....	1557.3	
Boring No. 41, made February 1st 8th, Station 10 + 83.		
Top of sand.....	1612.7	
Through fine sand and coal 35 feet to gravel at.....	1577.7	
" gravel with lumps of dark clay 13.5 feet to fine dark sand at.....	1564.2	
" fine dark sand 4.3 feet to blue clay at.....	1559.9	
Into blue clay 5.7 feet to.....	1554.2	
Boring No. 42, made February 9th 16th, Station 11 + 33.		
Top of sand.....	1624.5	
Through fine sand with coal and gravel 36.2 feet to coarse sand at.....	1588.3	
" coarse sand 11 feet to gravel at.....	1577.3	
" gravel 2 feet to blue clay at.....	1575.1	
" blue clay .8 feet to fine dark sand at.....	1574.3	
" fine dark sand 13 feet to coarse sand at.....	1561.3	
" coarse sand 5.5 feet to coarse gravel at.....	1555.8	
" coarse gravel 3.2 feet to clay at.....	1552.6	
Into clay 6.5 feet to.....	1546.1	
Boring No. 43, made February 16th to March 8th, Station 11 + 83.		
Top of sand.....	1625.4	
Through fine sand and coal 34.7 feet to coarse sand, etc., at.....	1590.7	
" coarse sand and gravel 17.3 feet to fine sand at.....	1573.4	
" fine sand 4.3 feet to coarse sand at.....	1569.1	
" coarse sand and gravel 19.3 feet to blue clay at.....	1549.8	
Into blue clay 4.7 feet to.....	1545.1	
Boring No. 44, made March 9th-29th, Station 12 + 33.		
Top of sand.....	1625.1	
Through fine sand 26.1 feet to coal at.....	1599.0	
" coal 1.2 feet to coarse sand at.....	1597.8	
" coarse sand and pebbles 16.5 feet to fine sand at.....	1581.3	
" fine sand and coal 4.5 feet to coarse sand at.....	1576.8	
" coarse sand and pebbles 3.4 feet to blue clay at.....	1573.4	
" blue clay .6 feet to fine dark sand at.....	1572.8	
" fine dark sand 11 feet to coarse sand, etc., at.....	1561.8	
" coarse sand and gravel 9 feet to fine sand at.....	1552.8	
" fine sand and coal 6 feet to blue clay at.....	1546.8	
Into blue clay 1.5 feet to.....	1545.3	

APPENDIX F

ACCOUNT OF CEMENT USED

PORTLAND CEMENT

MANUFACTURED BY ALSEN & SONS, ITZHOE

Masonry

East abutment, - - - - -	8½ bbls.
Pier I, - - - - -	226 "
Pier II, - - - - -	398 "
Pier III, - - - - -	625 "
Pier IV, - - - - -	267 "
Total in masonry, - - - - -	1,524½ bbls

Concrete

Pier I, - - - - -	1,275 bbls
Caisson, Pier II, before sinking, - - - - -	1,426 "
Working chamber, shafts, &c., - - - - -	854 "
Caisson, Pier III, before sinking, - - - - -	1,357 "
Working chamber, shafts, &c., - - - - -	857 "
Cushing Pier, - - - - -	77 "
Total in concrete, - - - - -	5,846 bbls.

Miscellaneous, shortage and balance left over, 158½ "

Total, Alsen cement, 7,522, b bls.

K. B. & S. CEMENT

Masonry, Pier III, - - - - -	57 bbls.
" Pier IV, - - - - -	54 "
Shortage, - - - - -	9 "
Total, K. B. & S. Cement, - - - - -	120 bbls.
Total, Portland cement purchased, - - - - -	7,649 bbls.

AMERICAN NATURAL CEMENT

F. O. NORTON'S ROSENDALE CEMENT

Masonry, Pier I, - - - - -	366 bbls.
" Pier II, - - - - -	996 "
" Pier III, - - - - -	827 "
" Pier IV, - - - - -	252 "
Total in masonry, - - - - -	2,441 bbls.
Concrete, Pier IV, - - - - -	469 "
Shortage and miscellaneous, - - - - -	190 "
Total, Norton cement, - - - - -	3,100 bbls.

MILWAUKEE CEMENT

East abutment, - - - - -	96½ bbls.
Miscellaneous, - - - - -	1½ "
Total, Milwaukee cement, - - - - -	98 bbls.
Total, American cement, - - - - -	3,198 bbls.
Total cement used, - - - - -	10,847 bbls.

APPENDIX G

SPECIFICATIONS FOR SUPERSTRUCTURE

GENERAL DESCRIPTION

There will be three spans of through bridge, each 400 feet long between centers, and two spans of deck bridge, each about 125 feet long.

In the through spans, the top chord, the end posts, the ten central panels of the bottom chord, the bolsters, rollers and bearing plates, and all pins of every description will be of steel; the other parts will be of wrought iron except the pedestal castings, the filling rings and portal ornaments, and the washer plates on lateral struts, which will be of cast iron. Each span will contain approximately 330,000 pounds of steel and 580,000 pounds of iron.

The deck spans will be entirely of wrought iron, except the pins, which will be of steel.

PLANS

Full detail plans, showing all dimensions, will be furnished by the Engineer of the bridge. The work will be built in all respects according to these plans. No allowance will be made to the contractor for any fitting of parts during erection, but he will be required to satisfy himself, by inspection of the plans, what fittings will be required.

The detail plans of the through spans will be ready for delivery to the contractor on the award of the work. The detail plans of the two deck spans will be ready on or before July 1st, 1881, and the Railroad Company reserves the right to change the length and other dimensions of these two spans at any time prior to that date, provided that the length shall not exceed 150 feet.

MATERIALS

All materials shall be subject to inspection at all times during their manufacture, and the Engineer and his inspectors shall be allowed full access to any of the works in which any portion of the materials are made.

The steel may be manufactured by the open-hearth process or by the Bessemer process, and laboratory tests shall be made of a sample bar rolled from a small ingot taken from every charge, and if this bar fails to meet the specifications the whole charge shall be rejected. Steel used in the compression members, bolsters, bearing-plates, pins and rollers shall contain not less than $\frac{3}{16}$ per cent. of carbon and less than $\frac{1}{4}$ of one per cent. of phosphorus. A round sample bar not less than $\frac{3}{4}$ inches diameter shall bend 180° around its own diameter without sign of crack or flaw. The same bar tested in a lever machine shall have an elastic limit of not less than 50,000, nor more than 55,000 pounds, and an ultimate strength of not less than 80,000, nor more than 90,000 pounds per square inch; it shall elongate at least 12 per cent. before breaking, and shall have a reduced area of 20 per cent. at the point of fracture.

Steel for rivets and eye-bars shall contain not less than $\frac{1}{16}$ per cent. of carbon, nor more than $\frac{1}{16}$ per cent. of phosphorus. A round sample bar not less than $\frac{3}{4}$ inch diameter shall bend 180° , and be set back on itself without showing crack or flaw; when tested in a lever machine it shall have an elastic limit of not less than 40,000, nor more than 45,000 pounds per square inch, and an ultimate strength of not less than 70,000, nor more than 80,000 pounds per square inch. It shall elongate at least 18 per cent., and

shall show a reduction of at least 30 per cent. at the point of fracture. In the finished full-sized bars, this steel shall have an elastic limit of at least 35,000 pounds per square inch, and an ultimate strength of at least 65,000 pounds per square inch, and shall elongate 10 per cent. before breaking.

Facilities for testing the sample bars shall be furnished by the contractor at a point convenient to the steel works, the test to be made at the expense of the contractor and under the direction of the Engineer of the bridge.

The iron used in the eye-bars and other tension members shall be double-rolled refined iron, or iron of at least equivalent character. It shall have an ultimate strength of 50,000 pounds per square inch, and an elastic limit of at least 26,000 pounds per square inch; it shall elongate at least 15 per cent., and show a reduced area of at least 25 per cent. at point of fracture. Small samples having a minimum length of at least 6 inches, which shall be prepared by the contractor, shall give the foregoing results. When tests are made of full sized bars, a reduction of from 5 to 10 per cent., according to the size of the bars, will be allowed, provided the character of the iron as shown by the fracture and by a uniformity of stretch is satisfactory. The fracture shall be of uniform fibrous character, free from any crystalline appearance.

Iron used in shapes, plates and other miscellaneous forms, when tested in small samples, which shall be prepared by the contractor, having a minimum length of 6 inches, shall show an elastic limit of at least 24,000 pounds, and an ultimate strength of at least 47,000 pounds per square inch, shall elongate at least 10 per cent. before breaking, and shall show a reduction of at least 15 per cent. in area at the point of fracture.

Cast iron shall be of the best quality of tough grey iron.

WORKMANSHIP

In riveted steel work the steel shall be punched with holes not larger than $\frac{1}{8}$ inch diameter, the several parts of each member shall then be assembled, and the holes shall be reamed to $\frac{1}{8}$ inch diameter, at least $\frac{1}{16}$ inch being taken out all around. The sharp edge of the reamed hole shall be trimmed, and the parts shall be riveted together without taking apart. All rivets in steel members shall be of steel; they shall be of such size that they will fill the hole before driving, and, whenever possible, shall be driven by power. All bearing surfaces shall be truly faced; the beveled surfaces on the end posts and end chord sections shall be truly faced so as to allow $\frac{1}{16}$ inch play in erection. The chord pieces shall be fitted together in the shop in lengths of at least five panels and marked; when so fitted together, there shall be no perceptible wind in the length laid out. The pin-holes shall be bored truly, so as to be equally distant, truly parallel with one another and at right angles to the axis of the member.

All wrought iron work shall be punched to accurate templates with holes $\frac{1}{16}$ inch larger than the size of rivet, and when put together a cold rivet shall pass through every hole without reaming. So far as possible all rivets shall be driven by power. The holes for the rivets connecting the floor beams with the posts and with the bolsters, which must be driven after erection, shall be accurately reamed to a template.

The steel eye-bars shall be rolled by the Kloman process, unless some other process of manufacturing heads is approved by the Engineer. The contractor will be required to furnish

three additional bars of every size without charge, these bars to be tested at such place as the Engineer may select. If the tests are satisfactory, the expense attending them shall be paid by the Railroad Company. If the tests are unsatisfactory, the whole lot of bars shall be rejected. If, however, the tests indicate that the defect is one which can be removed by annealing, a second set of bars shall be annealed and then tested; if the tests of the annealed bars are satisfactory, then the whole set of bars shall be annealed. All steel bars shall be tested to 20,000 pounds per square inch before shipment. If contractors desire to make use of some other process they will be required, at their own expense, to satisfy the Engineer of its excellence by a series of tests, such as he shall direct.

The heads of the iron eye-bars and the enlarged ends for screws in laterals shall be formed by upsetting and forging to shape or by forging with a plate welded on the side. The character of the work must be such that the enlarged head or end will break the body of the bar. An extra number of bars, not exceeding six in all, shall be furnished for testing, besides small samples.

All pins shall be accurately turned to a gauge and shall be of full size throughout. All pin-holes shall be bored to fit the pins with a play not exceeding $\frac{1}{16}$ inch. These clauses apply to all lateral connections as well as the main connections of the truss.

All workmanship, whether particularly specified or not, must be of the best kind now in use in first-class bridge work. Flaws or surface imperfections or irregular shapes will be sufficient ground for rejection of material.

All iron and steel work shall be painted with one coat of Cleveland Iron Clad Paint (purple brand) before it leaves the shop.

TERMS

The Railroad Company will furnish free transportation for men, tools and materials from St. Paul or from Duluth to Bismarck, and from Bismarck on completion of the work to either of these points.

The contractor will be required to furnish all false work and tools of every description, and to erect the bridge superstructure.

The contractor will be required, under a penalty of \$250 a day, to have the work completed and ready for the track on or before July 1st, 1882.

PRICES

Proposals for this work should be by the pound for three classes of materials delivered at the bridge site, namely: *Steel* per pound, *wrought iron* per pound, *cast iron* per pound; the prices to include all patterns and other work of every description. Cast iron includes the large pedestals and filling rings and portal plates; the cast washer plates riveted to the lateral struts will be classed as wrought iron.

Also a single gross sum for the erection of the entire superstructure.

No material will be paid for which does not form a part of the permanent structure.

The right is reserved to accept any proposal for material delivered at the bridge site with out erection.

APPENDIX H

DESCRIPTION AND STRENGTH OF FLOOR SYSTEM

The iron floor system consists of the cross floor beams placed at the panel points, or 25 feet between centers. Thirteen of these floor beams in each span are riveted to the vertical posts; two are suspended from the jigs at the tops of the end posts, and two rest upon pedestals back of the end posts. Between the floor beams are placed two longitudinal stringers, spaced 9 feet between centers; these stringers are riveted through the web plates of the cross floor beams.

STRENGTH OF STRINGERS

Each track stringer is composed of a web plate 30 by $\frac{5}{8}$ inches, and four angles 5 by $3\frac{1}{2}$ by $\frac{5}{8}$ inches, the depth over all being 30 $\frac{1}{2}$ inches. These stringers are designed to carry 100,000 pounds (50,000 pounds on each stringer) on a length of 20 feet, besides their own weight and the weight of the floor, with a maximum strain in the extreme fibers not exceeding 8,000 pounds per square inch of gross section, or 9,000 pounds per square inch of net section after deducting the rivet holes. The calculations of these strains are as follows:

A uniformly distributed load of 5,000 pounds per lineal foot on a length of 20 feet, or a load of 50,000 pounds on 20 feet of each stringer, will produce a bending moment at the center $M_1 = 8,250,000$.

The weight of one stringer is 3,400.

One-half the weight of track and floor, 225 lbs. per foot, makes the total dead weight carried by one girder 9,025 pounds, and the bending moment produced by the dead weight alone

$$M_2 = \frac{9,025 \times 300}{8} = 338,437.$$

The total bending moment is

$$M_{\text{max}} = M_1 + M_2 = 8,588,437.$$

The moment of inertia of the gross section of the stringers is

$$I = \frac{1}{12} [(8 \times 30^3) + 10 (30^3 - 29\frac{1}{2}^3) + 12 (39\frac{1}{2}^3 - 38^3)] = 10,890.$$

The moment of resistance is

$$R = \frac{4,888}{15\frac{1}{2}} = 321.$$

The maximum strain per square inch on extreme fibers is

$$\frac{M_{\text{max}}}{R} = 8,054.$$

If we deduct the rivet holes, we have

$$I_n = 4,888 - \frac{1}{12} [12 (27\frac{1}{2}^3 - 25\frac{1}{2}^3)] = 4,393.$$

and the moment of resistance becomes

$$R_n = \frac{4,393}{15\frac{1}{2}} = 288.$$

The tensile strain per square inch of net section on extreme fibers of bottom flange is

$$\frac{M_{\text{max}}}{R_n} = 8,988.$$



The end stringers in the end floor beams are 26 feet 2 inches long between bearings, and the flanges are composed of angle irons $3\frac{1}{2}$ by 5 by $\frac{5}{8}$ inches.

STRENGTH OF FLOOR BEAMS

Each of the thirteen intermediate floor beams consists of a web plate 39 by $\frac{5}{8}$ inches, four angles $3\frac{1}{2}$ by 5 by $\frac{5}{8}$ inches, and two cover plates 12 by $\frac{5}{8}$ inches and 14 feet long.

These floor beams are assumed to carry a moving load of 100,000 pounds, which is transferred to the beams by the stringers at points 9 feet apart, besides the weight of the stringers and floor upon them and the weight of the floor beam itself. The length of the floor beam is estimated at 21 feet, which is 2 inches more than the greatest distance between posts. For convenience in calculations the weight of the floor beams is supposed to be concentrated at the points where the attachments to the stringers are made, a supposition which, though not strictly accurate, is as nearly correct as to suppose the weight uniformly distributed. The weight of one pair of stringers and the floor upon them is 18,050 pounds, and the weight of one floor beam is estimated as 2,750 pounds, making a total dead load of 20,800 pounds.

The maximum bending moment produced by the live load is

$$M_1 = 50,000 \times 72 = 3,600,000.$$

The maximum bending moment produced by the dead load is

$$M_2 = 10,400 \times 72 = 748,800.$$

The total bending moment is

$$M_{\text{max}} = M_1 + M_2 = 4,348,800.$$

The moment of inertia of the gross section of the floor beam is

$$I = \frac{1}{12} [(8 \times 39^3) + 12 (39^3 - 39^3) + 10 (39^3 - 38^3) + (38^3 - 32^3)] = 10,890.$$

and the moment of resistance is

$$R = \frac{10,890}{19\frac{1}{2}} = 548.$$

The strain per square inch on the extreme fibers of gross section is

$$\frac{M_{\text{max}}}{R} = 7,936.$$

In deducting the rivet holes in the flanges, the rivet holes of the cover plates only should be deducted, as these rivets alternate with those connecting the angles with the web. The moment of inertia then becomes

$$I_n = I - \frac{1}{12} [12 (39^3 - 38^3)] = 9,733.$$

The moment of resistance becomes

$$R_n = \frac{9,733}{19\frac{1}{2}} = 490.$$

The tensile strain per square inch of net section on the extreme fibers of the bottom flange is

$$\frac{4,348,800}{490} = 8,875.$$



To make these calculations correct for the suspended floor beams, the length of the floor beam should be taken as 22 feet instead of 21 feet, and the distance from application of load to end supports as 78 inches instead of 72 inches. The increased bending moment due to this increase of length is provided for by making the cover plates 12 inches by $\frac{5}{8}$ inch and 16 feet long, the other dimensions being the same as in the intermediate floor beams.

The end floor beams carry only one-half a panel of floor instead of a whole panel. The greatest possible moving load which can be thrown upon them under the above supposition is

$$100,000 \text{ pounds} \times \frac{16.2}{26.2} = 61,832 \text{ pounds.}$$

In these floor beams the cover plate is omitted, the web and angles being the same size as in the other beams.

STRENGTH OF CONNECTIONS

The connections between the stringers and the cross floor beams are made through angle irons riveted to the webs of the stringers and of the floor beams; there are thirteen rivets in the connection between the angles and the web of the stringer and fourteen rivets, seven on each side, in the joint made with the web of the floor beam. The greatest shearing strain on the rivets occurs on those passing through the web of the floor beam when the moving load occupies the 20 feet of the stringer next the floor beam. The load then transferred by each joint is 34,512 pounds, or 2,465 pounds per rivet. These rivets being $\frac{3}{4}$ inches in diameter, the shearing section is 0.601 per rivet, making the shearing strain 4,100 per square inch. The greatest crushing strain on the rivet holes occurs in the web of the floor beam when the maximum moving load is transferred by this joint to the floor beam, the weight transferred by one joint being then 39,025 pounds, which distributed on fourteen rivets is 4,216 pounds per rivet, and the crushing surface is $\frac{3}{4}$ by $\frac{5}{8}$ inches, or $\frac{15}{32}$ inches, making the crushing strain per square inch 12,849 pounds.

The connection between the floor beams and the posts is made through angle irons, which are riveted to the web of the floor beam with seventeen rivets, and to the post with eighteen rivets, the holes for the latter being carefully reamed to 1 inch diameter after erection and before driving the rivets. The total weight transferred by each of these joints is 60,100 pounds. The greatest shearing strain occurs on the riveted connection of the beam to the post, being 3,361 pounds per rivet, which is equivalent to 4,282 pounds per inch on rivets of .785 inch section. The greatest crushing strain occurs in the web of the floor beam, being 3,559 pounds per rivet, equivalent to 10,846 pounds per square inch, the bearing surface of the rivet being $\frac{11}{16}$ inches.



APPENDIX I

STRAINS ON 400 FEET SPAN

RESULTANT STRAINS ON ONE RUSS FROM HEATING LOAD AS FOLLOWS ON BOTH CAUSSES												
DESCRIPTION				CASE I			CASE II					
PAGE	MATERIAL	THICKNESS	Tensile Section in Square Inches	Net on Tension in Square inches	FROM DEAD LOAD		Uniform Load of 4,000 per Foot, Live Load of 5,000 per Foot					
					Strain from Moving Load	Total Strain	Strain per Square Inch	Strain from Moving Load	Total Strain	Strain per Square Inch		
Lower Chord												
U ₁ L ₁	Iron	2 12" channels, 115 lbs. per yard	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂ L ₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃ L ₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄ L ₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅ L ₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆ L ₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇ L ₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈ L ₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₉ L ₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₀ L ₁₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₁ L ₁₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₂ L ₁₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₃ L ₁₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₄ L ₁₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₅ L ₁₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₆ L ₁₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₇ L ₁₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₈ L ₁₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₁₉ L ₁₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₀ L ₂₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₁ L ₂₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₂ L ₂₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₃ L ₂₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₄ L ₂₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₅ L ₂₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₆ L ₂₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₇ L ₂₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₈ L ₂₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₂₉ L ₂₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₀ L ₃₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₁ L ₃₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₂ L ₃₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₃ L ₃₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₄ L ₃₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₅ L ₃₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₆ L ₃₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₇ L ₃₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₈ L ₃₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₃₉ L ₃₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₀ L ₄₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₁ L ₄₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₂ L ₄₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₃ L ₄₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₄ L ₄₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₅ L ₄₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₆ L ₄₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₇ L ₄₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₈ L ₄₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₄₉ L ₄₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₀ L ₅₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₁ L ₅₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₂ L ₅₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₃ L ₅₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₄ L ₅₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₅ L ₅₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₆ L ₅₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₇ L ₅₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₈ L ₅₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₅₉ L ₅₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₀ L ₆₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₁ L ₆₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₂ L ₆₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₃ L ₆₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₄ L ₆₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₅ L ₆₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₆ L ₆₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₇ L ₆₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₈ L ₆₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₆₉ L ₆₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₀ L ₇₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₁ L ₇₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₂ L ₇₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₃ L ₇₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₄ L ₇₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₅ L ₇₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₆ L ₇₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₇ L ₇₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₈ L ₇₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₇₉ L ₇₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₀ L ₈₀	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₁ L ₈₁	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₂ L ₈₂	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₃ L ₈₃	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₄ L ₈₄	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₅ L ₈₅	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₆ L ₈₆	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₇ L ₈₇	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₈ L ₈₈	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₈₉ L ₈₉	"	2 12" "	27	27	117,200	116,000	247,800	1,200	140,000	277,800	10,100	
U ₉₀ L ₉₀	"	2 12" "</										

APPENDIX J CONTINUED

HIGH, OR COMPRESSION, STEEL MANUFACTURED BY THE SPANG STEEL AND IRON COMPANY LIMITED CONTINUED

NOTE. Specimen Nos. 1X, 20X, 21X, 22X and 23X were all prepared from the testing and turned to the diameter given. No. 23X by the use of No. 20X, so that no reduction of area or extension could be taken.

APPENDIX K—CONTINUED

No. OF TEST, 1825.					No. OF TEST, 1826.	
Loads applied	Lbs. per square inch	Elongation	Set	Remarks	Sectional area, sq. in.	Gauged length, in.
8,380	1,000	0.155"			7.87	1.00
13,800	10,000	0.866"			7.87	1.00
124,700	15,000	1.32"			7.87	1.00
167,600	20,000	1.784"			7.87	1.00
209,500	25,000	2.257"			7.87	1.00
215,000	1,000	2.33"			7.87	1.00
216,000		2.342"			7.87	1.00
223,000		2.440"			7.87	1.00
227,000		2.488"			7.87	1.00
231,000		2.540"			7.87	1.00
235,000		2.588"			7.87	1.00
239,000		2.641"			7.87	1.00
243,000		2.690"			7.87	1.00
247,000		2.740"			7.87	1.00
251,400	30,000	2.800"			7.87	1.00
254,000	1,000	2.878"			7.87	1.00
257,000		2.918"			7.87	1.00
263,000		2.99			7.87	1.00
266,000		3.000"			7.87	1.00
269,000		3.042"			7.87	1.00
272,000		3.093"			7.87	1.00
275,000		3.140"			7.87	1.00
278,000		3.196"			7.87	1.00
281,000		3.270"			7.87	1.00
284,000		3.317"			7.87	1.00
287,000		3.388"			7.87	1.00
290,000		3.440"			7.87	1.00
293,300	35,000	3.500"			7.87	1.00
301,680	1,000	3.574"			7.87	1.00
318,440	35,000	3.690"			7.87	1.00
494,000					7.87	1.00
519,400					7.87	1.00
520,000					7.87	1.00
520,900	63,230				7.87	1.00
520,000		3.705"			7.87	1.00
Elongation c. to c. of eyes, 40 13' — 13.4 8'.					No. OF TEST, 1826.	
" of eyes: A 56", B 90".					No. OF TEST, 1826.	
" 10" sections: 80", 84", 99", 1.09", 1.25", 1.48", 1.37", 1.29", 1.25", 1.38", 1.50", 1.46", 1.46", 1.46", 1.30", 1.17", 1.31", 1.55", 1.78", 1.52", 1.60", 1.85", 2.68", 2.13", 1.30", 1.04", 1.10", 78".					No. OF TEST, 1826.	
Area at fracture, 5 65" x 1.04" = 5.88 sq. in.					No. OF TEST, 1826.	
Contraction of area, 29.8'.					No. OF TEST, 1826.	
Fracture occurred 662" from center of eye A.					No. OF TEST, 1826.	
Centre D has silvery color; presents a face about 45° to plane of stem. Sides of fracture granular, radiating from the center.					No. OF TEST, 1826.	
Time of test, 2 1/2 hours.					No. OF TEST, 1826.	
Note.—The pins for this bar were so placed as to straighten the permanent deflection recorded after test No. 1822.					No. OF TEST, 1826.	
Pins now deflected in their new position: A .006", B .005".					No. OF TEST, 1826.	

Elongation c. to c. of pin holes, 24.48" = 8.2 2%.

" of eyes: A 55", B 64".

" 10" sections: 75", 77", 87", 95", 99", 92", 86", 77", 75", 81", 97", 82", 87", 91", 94", 90", 85", 84", 82", 85", 78", 90", 1.20", 80", 68", 57", 66", 60".

Area at fracture, 6.16" x 1.08" = 6.65 sq. in.

Contraction of area, 15.5'.

Fractured 74" from center of eye A.

Appearance of fracture: silky for about 2" at center; slightly spongy; on either side fine granular, radiating from center, with slight lamination.

The behavior of the bar between loads 335,000 and 350,000 lbs. showed that stretching was not progressing uniformly; that section by section of the stem which varied in area was being stretched rapidly.

Time of test, 3 hours.

No. OF TEST, 1826.					No. OF TEST, 1826.	
Loads applied	Lbs. per square inch	Elongation	Set	Remarks	Sectional area, sq. in.	Gauged length, in.
74,000	1,000	0.389"			7.40	1.00
74,000	5,000	0.840"			7.40	1.00
111,000	15,000	1.298"			7.40	1.00
148,000	20,000	1.743"			7.40	1.00
158,000	25,000	2.214"			7.40	1.00
189,000	1,000	2.270"			7.40	1.00
192,000		2.310"			7.40	1.00
195,000		2.350"			7.40	1.00
198,000		2.390"			7.40	1.00
201,000		2.430"			7.40	1.00
204,000		2.470"			7.40	1.00
207,000		2.510"			7.40	1.00
210,000		2.551"			7.40	1.00
213,000		2.590"			7.40	1.00
216,000		2.638"			7.40	1.00
219,000		2.674"			7.40	1.00
222,000	30,000	2.720"			7.40	1.00
224,000	1,000	2.754"			7.40	1.00
226,000		2.791"			7.40	1.00
228,000		2.818"			7.40	1.00
230,000		2.850"			7.40	1.00
232,000		2.875"			7.40	1.00
234,000		2.910"			7.40	1.00
236,000		2.945"			7.40	1.00
238,000		2.979"			7.40	1.00
240,000		3.005"			7.40	1.00
242,000		3.030"			7.40	1.00
244,000		3.059"			7.40	1.00
246,000		3.130"			7.40	1.00

Elongation c. to c. of eyes, 16.44" — 5.5 %.

" of eyes: A, .50"; B, .57".

" 10" sections: .50", .48", .49", .49", .50", .50", .51", .49", .53", .55", .58", .60", .60", .55", .58", .55", .60", .59", .57", .60", .62", .57", .59", .55", .50", .45".

Area at fracture, 6.44" × 1.56" = 10.05 sq. in.

Contraction at area, 6.7 %.

Fractured 6 1/2" from center of eye A.

Appearance: granular, radiating from small (1/4" × 1/2") spongy center; spongy spot about 1/2" out of center of fracture. Broke square across bar.

Time of test, 2 1/2 hours.

WATERTOWN ARSENAL, MASS., Feb. 20, 1882

No. OF TEST, 1839.

End B (annealed) painted, end A (not annealed) not painted.

Gauged lengths of 80" each were laid off on the stem, one on the annealed end, and one on the unannealed end, these sections beginning 40" each side of the middle of the bar. Stem laid off into 10" sections from head to head.

End A, minimum sectional area ii. gauged length, 6.58" × .97" = 6.38 sq. in.

End B, minimum sectional area in gauged length, 6.44" × .97" = 6.25 sq. in.

Loads applied	END A				END B				REMARKS
	Lbs. per Sq. Inch	Elongation	Set		Lbs. per Sq. Inch	Elongation	Set		
1 320	1,000								
31,600	5,000	0160"				0160"			
63,200	10,000	0300"				03 3"			
1 320	1,000								
91,800	15,000	0431"				4 "			
121,400	20,000	0562"				5 72"			
151,000	25,000								
180,600	30,000	0700"				6 "			
210,200	35,000								
239,800	40,000	0725"				0730"			
269,400	45,000	0754"				0750"			
299,000	50,000	0777"				0775"			
328,600	55,000	0780"				0788"			
358,200	60,000	0800"				0800"			
387,800	65,000	0819"				0811"			
417,400	70,000	0834"				0823"			
447,000	75,000	0845"				0845"			
476,600	80,000	0858"				0862"			
506,200	85,000	0871"				0874"			
535,800	90,000	0880"				0883"			
565,400	95,000	0890"				0892"			
595,000	100,000	0900"				0900"			
624,600	105,000	0910"				0910"			
654,200	110,000	0928"				0926"			
683,800	115,000	0938"				0938"			
713,400	120,000	0947"				0947"			

APPENDIX K—CONTINUED

Loads applied	END A				END B				Remarks
	Lbs. per Sq. Inch	Elongation	Set		Lbs. per Sq. Inch	Elongation	Set		
2,000		0057"				0053"			
218,000		0076"				0060"			
236,000		0078"				0070"			
254,000		0084"				0075"			
272,000	35,000		0037"						
290,000		1000"				0085"			
308,000		1008"				0095"			
326,000		1017"				0108"			
344,000		1030"				0102"			
362,000		1040"				0100"			
380,000		1050"				0075"			
398,000		1062"				0105"			
416,000		1075"				0100"			
434,000		1092"				0100"			
452,000		1105"							
470,000	38,610								
488,000		11 1/2"							
506,000		1250"							
524,000		1250"							
542,000		1265"							
560,000	1,000								
578,000		2 2"							
596,000		12 1/2"							
614,000	54,980								
632,000		2 40'							

Time of test, 2 1/2 hours.

Fractured in head A.

Elongation of 10" sections, beginning at end A: .43", .44", .40", .39", .37", .35", .31", .28", .21", .24", .25", .24", .42" (annealing begins), .38", .37", .35", .40", .35", .40", .53", .50", .51", .56", .58", .50", .54", .55".

Elongation of eyes: A about .19", B .66".

Area at middle of bar, 6.58" × 1.1" = 6.64 sq. in.

Elongation c. to c. of eyes, 12.07" = 4 %.

Rapid stretching, end B, began at the neck, 12" from center of eye. The scale at this end was not generally disturbed till 240,000 lbs. total load was reached.

Broke through eye A.

Side fractures fine granular, radiating from the pin hole.

Fracture in front of eye, not extending to the outside of head, granular radiating from pin-hole.

Bar again placed in the testing machine.

End A clamped in holder.

" B held by pin.

Ultimate strength, 396,500 lbs. = 63,440 lbs. per sq. in. on end B.

Fractured 5 1/2" from center of eye B.

Elongation of 10" sections, beginning at end A (first section covered by clamp of holder): 1.00", .89", .77", .71", .68", .42", .44", .41", .45", .46", .45", .90" (annealing begins), .78", .69", .64", .74", .64", .66", .84", .1.40", .1.27", .1.40", .1.71", .3.37", .1.37", .1.69", .1.79".

Area at fracture, 5.09" × .74" = 3.77 sq. in.

Contraction of area, 39.7 %.

Elongation of eye B, 1.08".

Appearance of fracture: silky, with slight lamination and occasional bright spots. When fractured ends are brought together and in line, contact is made on one edge, the other edge remaining open .35".

The stem of the bar now cut in two at the middle, nicked with a cold chisel 1/2" off, and broken by bending. This developed lamination more conspicuously than the tensile test had done.

After the bar had rested 36 hours (Saturday till Monday), it was placed in the testing machine, each end being held by the holder clamps.

Ultimate strength, 422,700 lbs. = 66,880 lbs. per sq. in. for end A.

Elongation of 10" sections, beginning at the second section, end A: 3.07", .1.42", .1.10", .1.00", .94", .59", .60", .56", .60".

Area at fracture, 5.25" × .77" = 4.04 sq. in.

Contraction of area, 36.1 %.

Broke 25" from center of eye A.

Fracture granular 60% at the sides, radiating from the center. Central part of the fracture silky 40%, wedge-shaped at one end, with a corresponding recess in the other end.

Load on bar at time of fracture, 388,000 lbs.

Rested 26 days and again tested.

Ends secured in holder jaws.

Rapid stretching began at 440,000 lbs.

Ultimate strength, 448,000 lbs. = 65,400 lbs. per sq. in. on the original section of (6.65" × 1.03") 6.85 sq. in.

Area at fracture, 5.88" × .74" = 4.35 sq. in.

Contraction of area (from original), 36.5 %.

This fracture occurred 180" from center of eye B, hence was within the section where the change from annealing to unannealing was made. The rapid stretching was confined mostly at the fracture, and did not extend from this point beyond 30" towards end B.

Appearance: silky 85 %; granular 15 % at one side; laminated metal.

To get a fracture wholly within the annealed section, the bar was again placed in the testing machine and broken.

Ultimate strength, 440,000 lbs. = 70,400 lbs. per sq. in. on original section of 6.25 sq. in.

Bar broke 69" from center of eye B without further elongation, except the drawing down at the point of fracture.

Area at fracture, 5.42" × .81" = 4.71 sq. in.

Contraction of area (from original), 24.7 %.

Appearance: at middle silky 40 %, granular 60 % radiating from center.

Elongation c. to c. of eyes, 10.49" — 3 5 %.

" of 10' sections: 28", 34", 29", 32", 35", 35", 34", 35", 38", 36",
38", 36", 39", 41", 40", 40", 40", 39", 39", 40", 40", 40", 39", 39", 33",
32", 33", 29"

Elongation of eyes. A 30", B about 30".

Broke across head B.

Appearance, granular, radiating from pin-hole.

Outside edge of fracture has hard appearance.

SEPTEMBER 13, 1882.

SUPPLEMENTARY TEST OF No. 2605.

End A secured by its pin through eye.

End B secured in jaws of holder between flat friction plates.

APPENDIX K—CONTINUED

Time	Load	Remarks
5" . .	53,570	Stretching began.
5" . .	55,450	Rapid stretching began.
5" . .	58,220	Slipped in jaws of holder 13", accompanied by report loud as when bars of this size fracture.
5" . .		Load on bar after slipping took place.

Total elongation of eye A, .50"

" " " 10' sections 41", .50", .47", .49", .51", .51", .51", .58", .59", .59",
.58", .56", .55", .59", .59", . . 58", .57", .50", .50", .50", 41"

REMARKS

Two sheets of emery cloth No. 90 placed above and below eye-bar, also two sheets between each flat plate. The slipping occurred between the sheets of cloth used next the eye-bar.

Co-efficient of friction at time of slipping, .309.

Load, 27,000 lbs. per square inch on friction surfaces.

APPENDIX L

ANALYSES OF BARS TESTED AT WATERTOWN

Number of Pile	CHEMICAL ANALYSES OF STEEL WELDED JOINTS							CHEMICAL ANALYSES OF STEEL WELDED JOINTS							SUMMARY OF RESULTS OF METALLURGICAL TESTS AT WATERTOWN							REMARKS		
	TENSILE TEST							TENSILE TEST							TENSILE TEST									
	TENSILE TEST							TENSILE TEST							TENSILE TEST									
	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Copper	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Copper	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Copper	Carbon	Manganese	Phosphorus		Sulphur	Silicon
1820	0.270	0.482	0.115	0.019	0.34	0.071	0.25	0.49	0.127	0.041	0.019	0.075	0.2540	0.445	0.045	0.010	0.075	0.2540	0.445	0.045	0.010	27,119,000		
1821	0.110	0.471	0.130	0.021	0.027	0.016	0.100	0.480	0.144	0.014	0.025	0.011	0.1058	0.486	0.045	0.010	0.011	0.1058	0.486	0.045	0.010	28,000,000		
1822	0.040	0.65	0.102	0.015	0.016	0.017	0.050	0.61	0.101	0.011	0.010	0.010	0.0400	0.61	0.045	0.010	0.010	0.0400	0.61	0.045	0.010	28,000,000	Far above beam	Not tested
1823	0.280	0.411	0.218	0.019	0.022	0.051	0.280	0.410	0.217	0.010	0.010	0.010	0.2800	0.410	0.045	0.010	0.010	0.2800	0.410	0.045	0.010	28,000,000	"	Idem
1824	0.260	0.418	0.114	0.011	0.011	0.019	0.260	0.410	0.110	0.011	0.011	0.011	0.2600	0.410	0.045	0.010	0.011	0.2600	0.410	0.045	0.010	27,000,000		
1825	0.210	0.455	0.114	0.017	0.011	0.010	0.210	0.450	0.121	0.017	0.011	0.011	0.2100	0.450	0.045	0.010	0.011	0.2100	0.450	0.045	0.010	28,000,000		
1826	0.130	0.481	0.13	0.015	0.010	0.010	0.130	0.480	0.130	0.010	0.010	0.010	0.1300	0.480	0.045	0.010	0.010	0.1300	0.480	0.045	0.010	27,000,000		
1827	0.200	0.571	0.101	0.018	0.010	0.010	0.210	0.570	0.111	0.010	0.010	0.010	0.2100	0.570	0.045	0.010	0.010	0.2100	0.570	0.045	0.010	28,000,000		
1828	0.230	0.481	0.119	0.014	0.010	0.011	0.230	0.480	0.111	0.010	0.010	0.010	0.2300	0.480	0.045	0.010	0.010	0.2300	0.480	0.045	0.010	28,000,000	Far below beam	Retested
1829	0.220	0.490	0.107	0.011	0.010	0.011	0.220	0.490	0.108	0.015	0.015	0.015	0.2200	0.490	0.045	0.010	0.015	0.2200	0.490	0.045	0.010	28,000,000	"	Not tested
1830	0.160	0.510	0.085	0.011	0.010	0.010	0.160	0.510	0.081	0.011	0.011	0.011	0.1600	0.510	0.045	0.010	0.011	0.1600	0.510	0.045	0.010	28,000,000	"	Retested
1831	0.250	0.560	0.124	0.011	0.010	0.011	0.250	0.560	0.121	0.010	0.010	0.010	0.2500	0.560	0.045	0.010	0.010	0.2500	0.560	0.045	0.010	28,000,000		
1832	0.210	0.550	0.107	0.012	0.010	0.010	0.210	0.550	0.121	0.010	0.010	0.010	0.2100	0.550	0.045	0.010	0.010	0.2100	0.550	0.045	0.010	28,000,000		
1833	0.200	0.517	0.141	0.011	0.010	0.010	0.200	0.510	0.140	0.010	0.010	0.010	0.2000	0.510	0.045	0.010	0.010	0.2000	0.510	0.045	0.010	28,000,000		
1834	0.180	0.510	0.111	0.010	0.010	0.010	0.180	0.510	0.110	0.010	0.010	0.010	0.1800	0.510	0.045	0.010	0.010	0.1800	0.510	0.045	0.010	28,000,000		
2134	0.200	0.51	0.104	0.010	0.010	0.010	0.200	0.510	0.110	0.010	0.010	0.010	0.2000	0.510	0.045	0.010	0.010	0.2000	0.510	0.045	0.010	28,000,000		
2135	0.260	0.571	0.109	0.010	0.010	0.010	0.260	0.570	0.110	0.010	0.010	0.010	0.2600	0.570	0.045	0.010	0.010	0.2600	0.570	0.045	0.010	28,000,000		
2605	0.190	0.570	0.097	0.011	0.010	0.010	0.190	0.570	0.097	0.010	0.010	0.010	0.1900	0.570	0.045	0.010	0.010	0.1900	0.570	0.045	0.010	28,000,000	Far above beam	Not tested

APPENDIX M

REPORT OF TESTING COMMITTEE

To GEO. S. MORISON, Esq.,
Chief Engineer, Bismarck Bridge.

DEAR SIR:

Having been present as a committee to witness the testing of the Bismarck Bridge, we subjoin the following

REPORT

The Bismarck Bridge, across the Missouri at this place, is a single track bridge, and affords a passage for the traffic of the N. P. R. R. across that river.

It consists of three through spans and two deck spans, in the following order:

Beginning near the foot of the bluff, on the east side of the river, the first span is an inverted bowstring 113 feet long.

The second, third and fourth spans are of the Pratt truss principle, each 400 feet long and 50 feet deep, center to center of pins. The fifth span is of the same dimensions as the first.

For the remaining distance across the flat land, the rails are temporarily carried on wooden trestle-work. The work of filling in around this trestle to form a permanent embankment approach is now in progress.

The material in each main span consists of 348,797 lbs. of steel, 600,950 lbs. of wrought iron, 25,777 lbs. of cast iron, distributed as follows:

Upper chords, end posts (all but three panels at each end of the lower chords), and all the pins are of steel. The bed-plates on the piers are of cast iron. The remaining portions are of wrought iron.

BISMARCK, DAKOTA, Oct. 21, 1882.

The following tables give the sections of the various members of the main spans. [See Plate 19.]

METHOD OF THE TEST

The load used in testing the spans consisted of eight Mogul locomotives, with their tenders, coupled together.

The weight of each, in the order in which they came upon the bridge, was as follows:

Order	Manufacturer's Name	No	Weight of Engine	Weight of Tender	Total Weight
1st	Baldwin	113	82,600	59,400	142,000
2d	"	108	83,800	58,500	142,300
3d	"	106	81,100	60,800	141,900
4th	"	79	83,100	61,200	144,300
5th	"	102	81,900	63,100	145,000
6th	"	104	81,900	37,400	119,300
7th	"	105	81,900	48,000	129,900
8th	"	114	81,900	49,000	130,900

Aggregate weight of eight engines, 1,077,400 lbs.

As the above train of engines covered a distance of over 400 feet, probably the actual load on each span was not more than 1,050,000 lbs., which, if uniformly distributed, would give an intensity for live load of $\frac{1,050,000}{400} = 2,625$ lbs. = 1.3125 tons per foot run.

The deflections were accurately determined (by means of leveling instruments) at each post of each truss, and the elongations of the lower chords noted carefully, with the results shown in the following diagrams. [See Plate 25.]

While the live load was on, the camber was not all taken out, and when the load was removed the spans regained their original camber and the lower chords their former length.

The engines passed on from the west end at 10.45 A. M., and the above test lasted about fifty minutes. At 11.50 A. M. the train of engines started from the east side, and ran over the bridge at the rate of about ten miles per hour.

In conclusion, we take pleasure in stating that, in our opinion, the arrangement of the materials and the character of the workmanship in these spans, and the quality of the masonry of piers and abutments, as well as the results of the above tests, are eminently satisfactory.

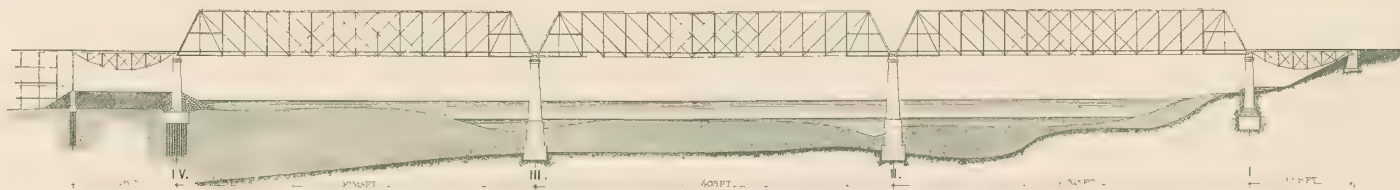
Signed,

L. L. BUCK,
J. B. CLOUGH,
FREDK. W. GILBERT,
F. N. FINNEY,
A. J. MERRITT,
WM. WATSON.

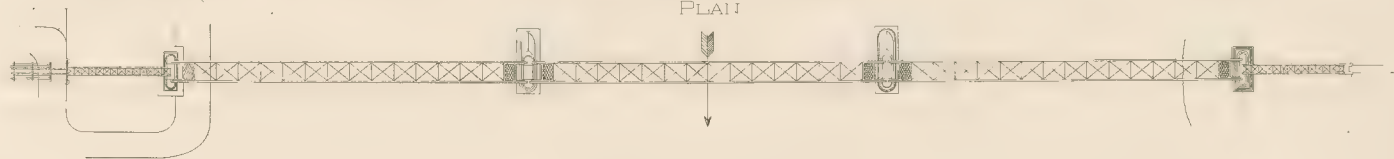
NORTHERN PACIFIC RAILROAD.

BISMARCK BRIDGE.

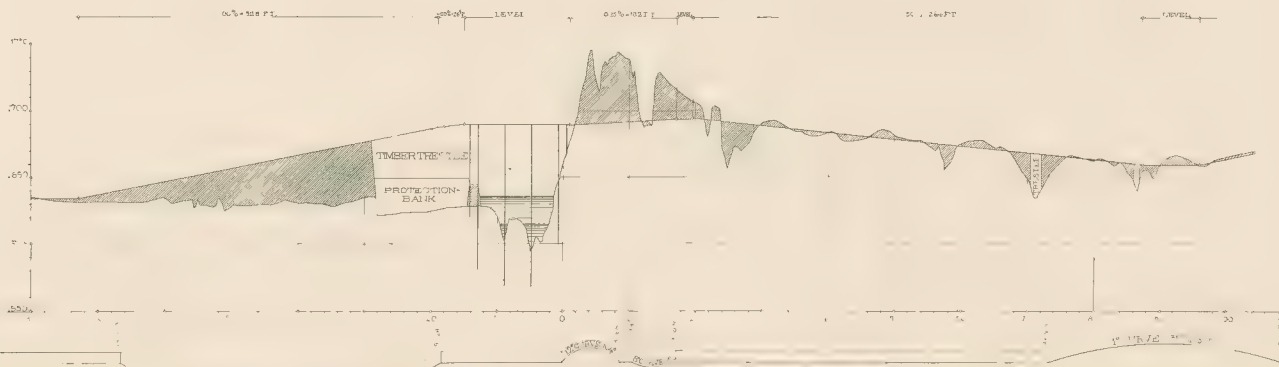
ELEVATION



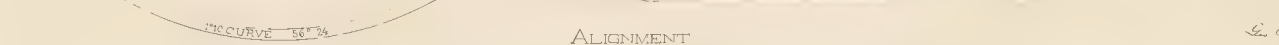
PLAN



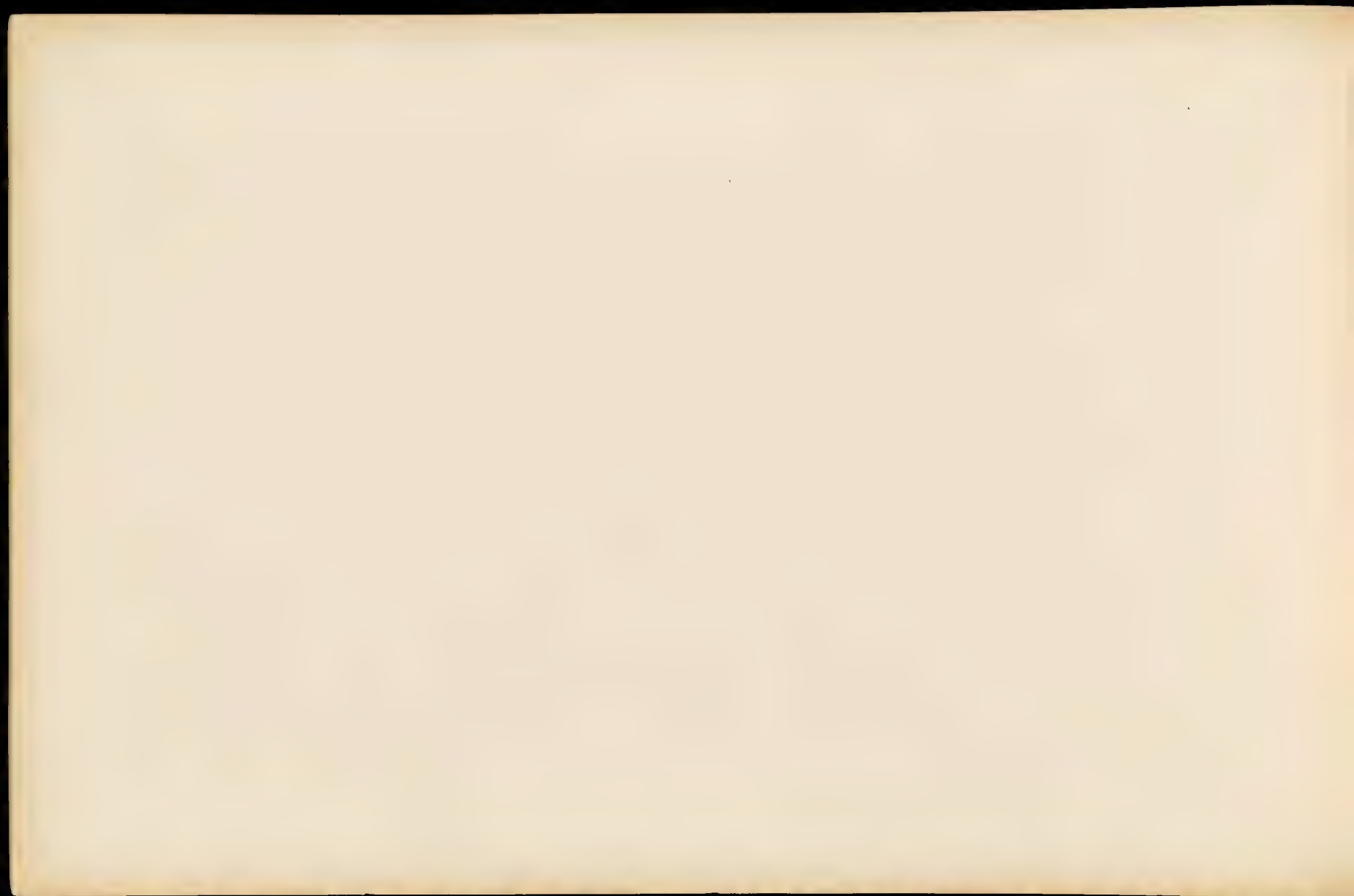
PROFILE



ALIGNMENT



E. S. Mousa
Eng. & Archt.

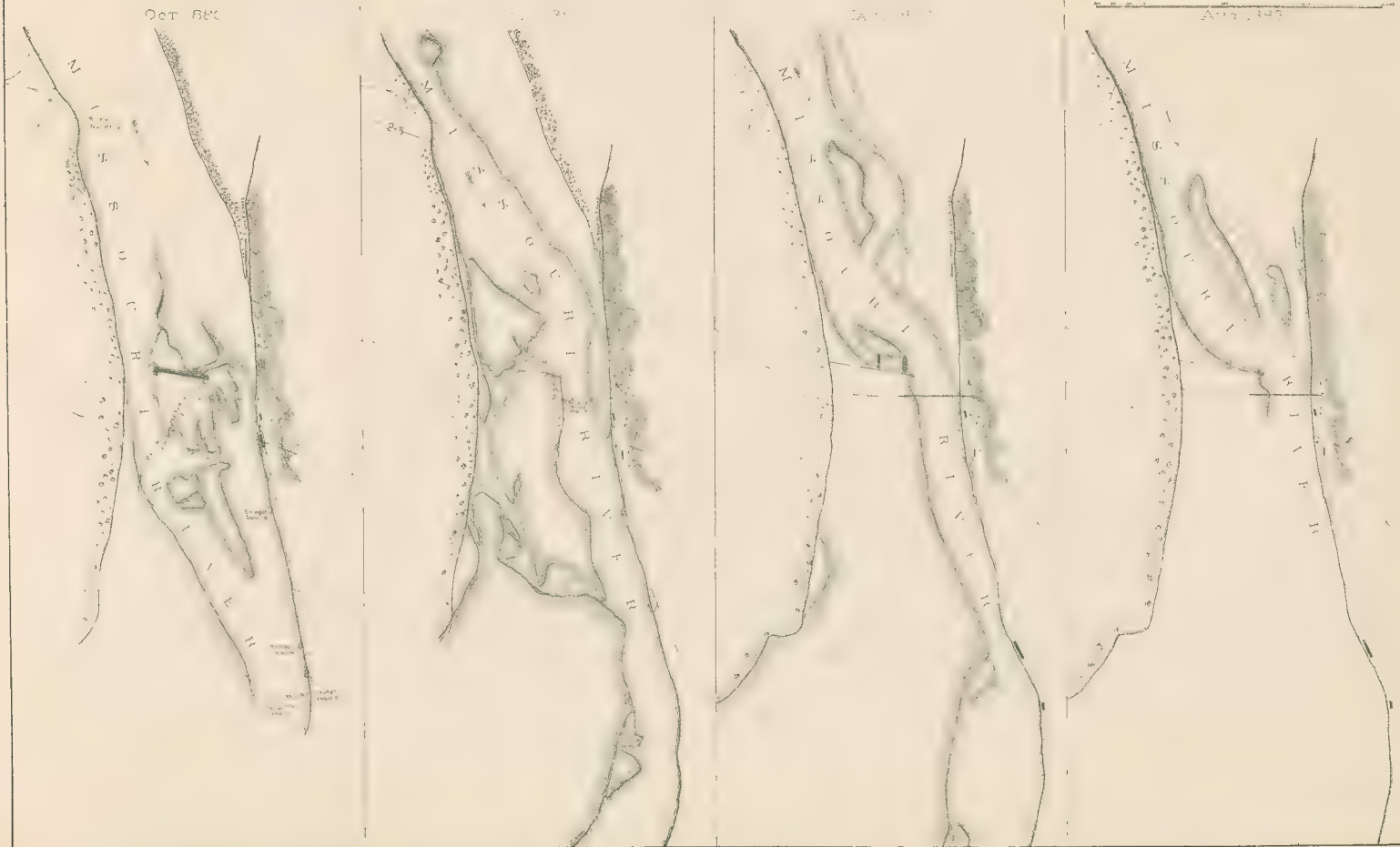


NORTHERN PACIFIC RAILROAD.

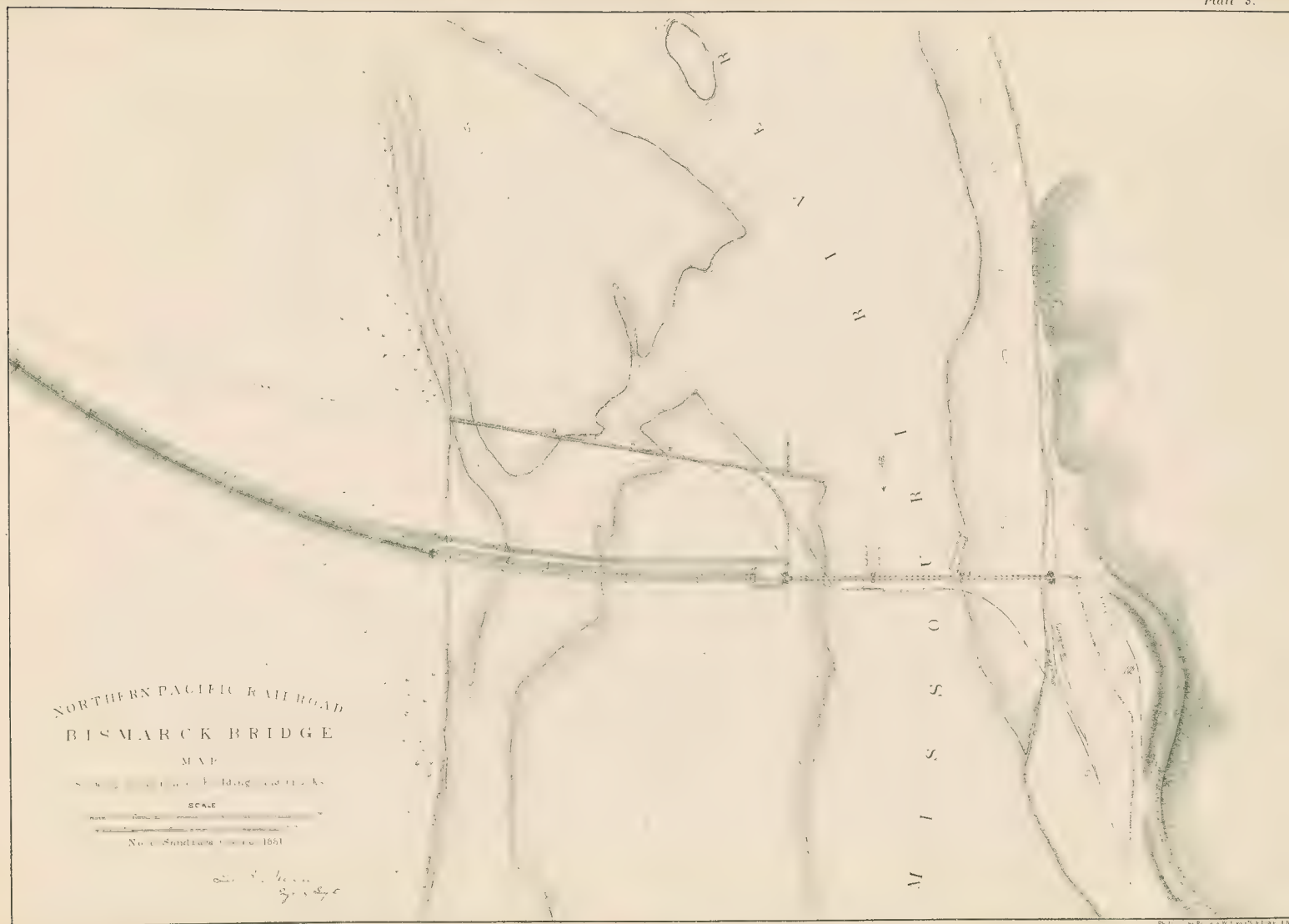
BISMARCK BRIDGE.

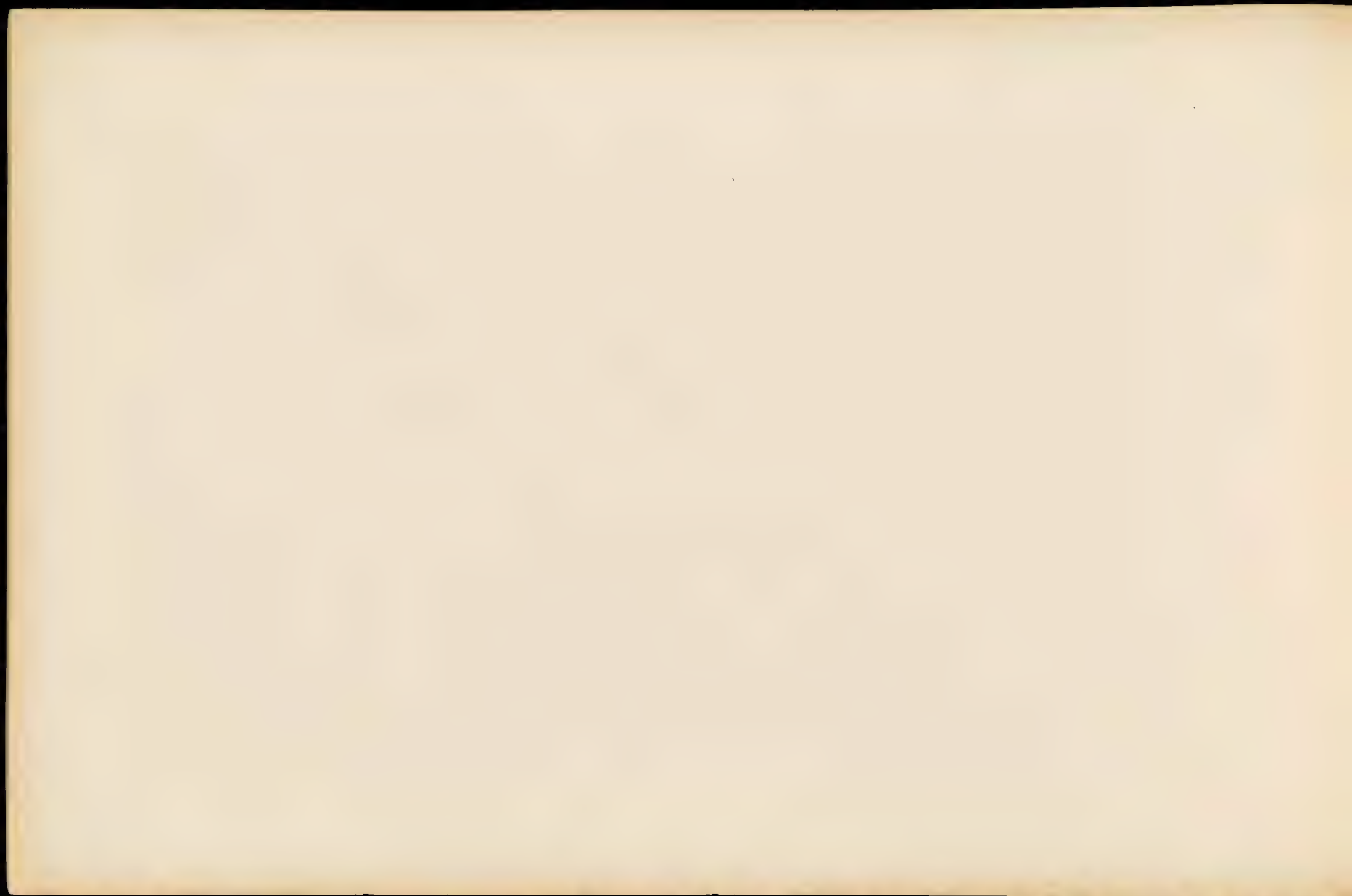
MAPS SHOWING POSITION OF SAND BARS AND CHANNEL

C. S. Meade
by J. S. Meade



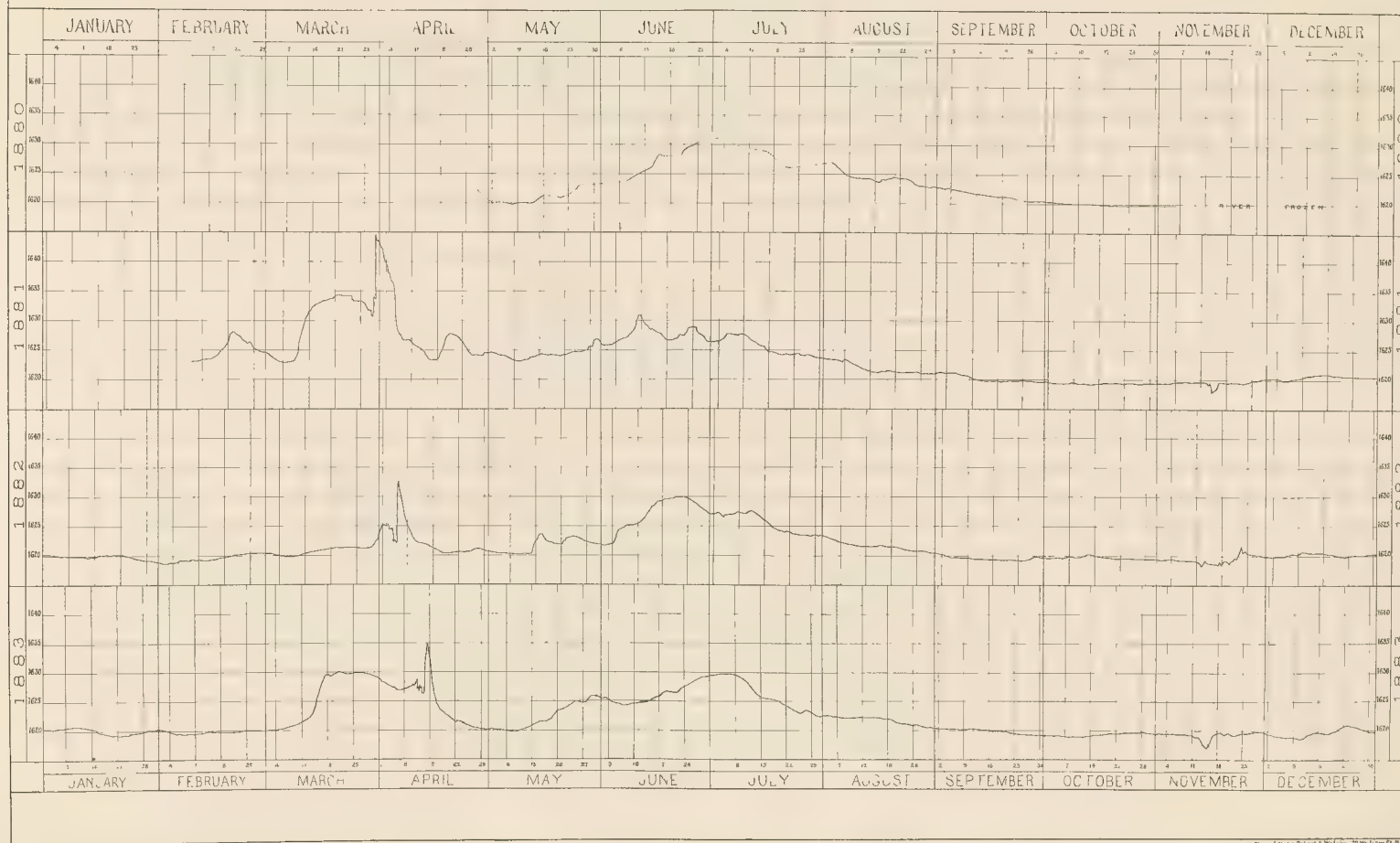


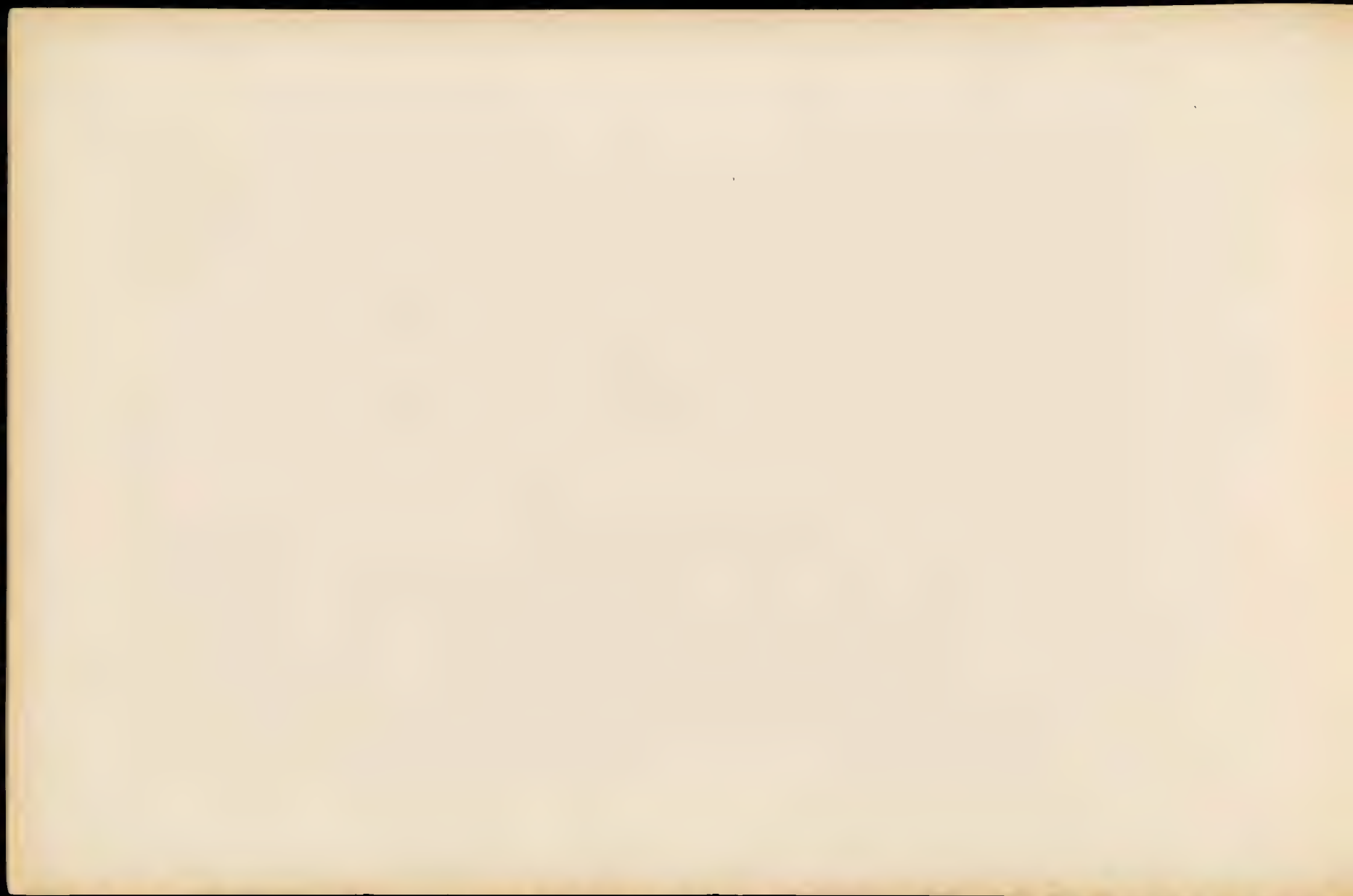


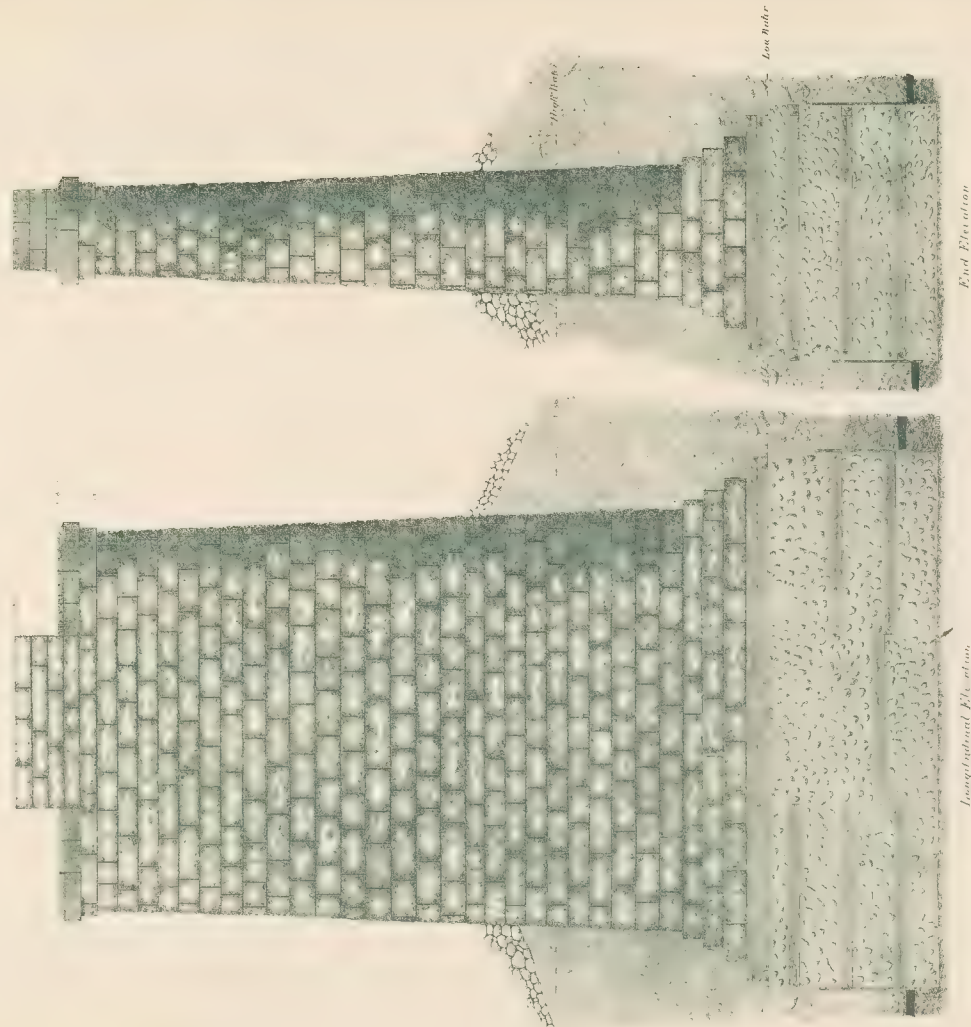


NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
WATER GAUGE OF THE MISSOURI RIVER AT BISMARCK D.T.

L. S. Munson
Engineer







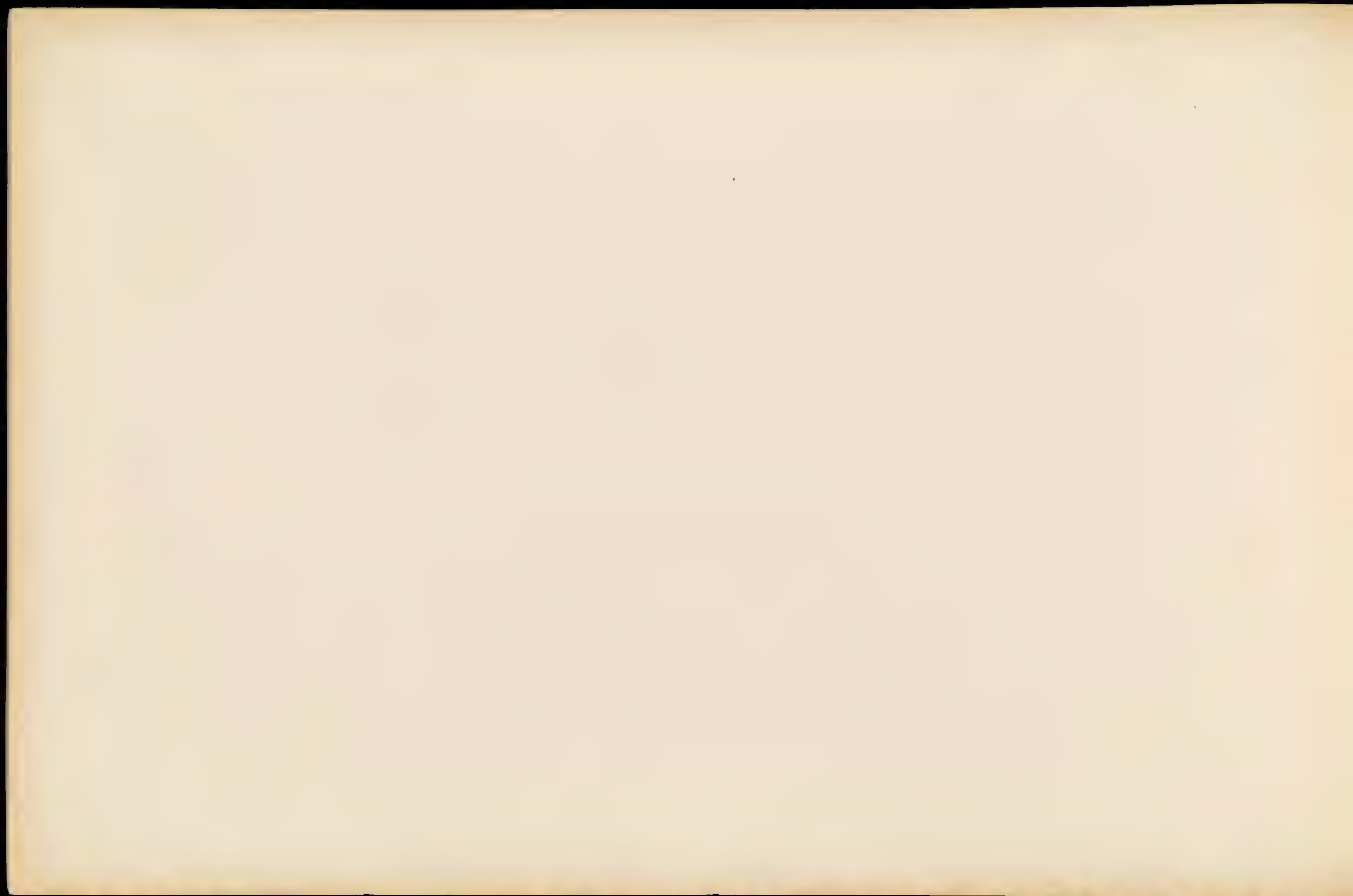
NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE

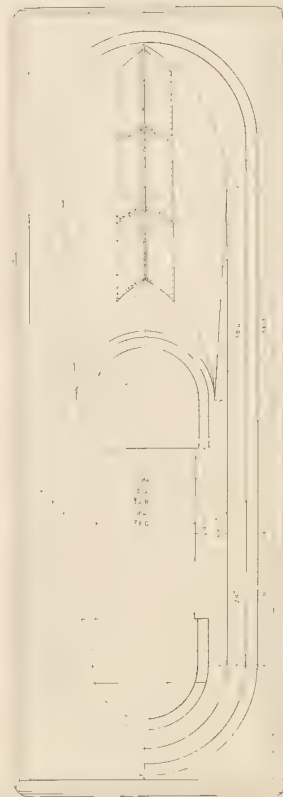
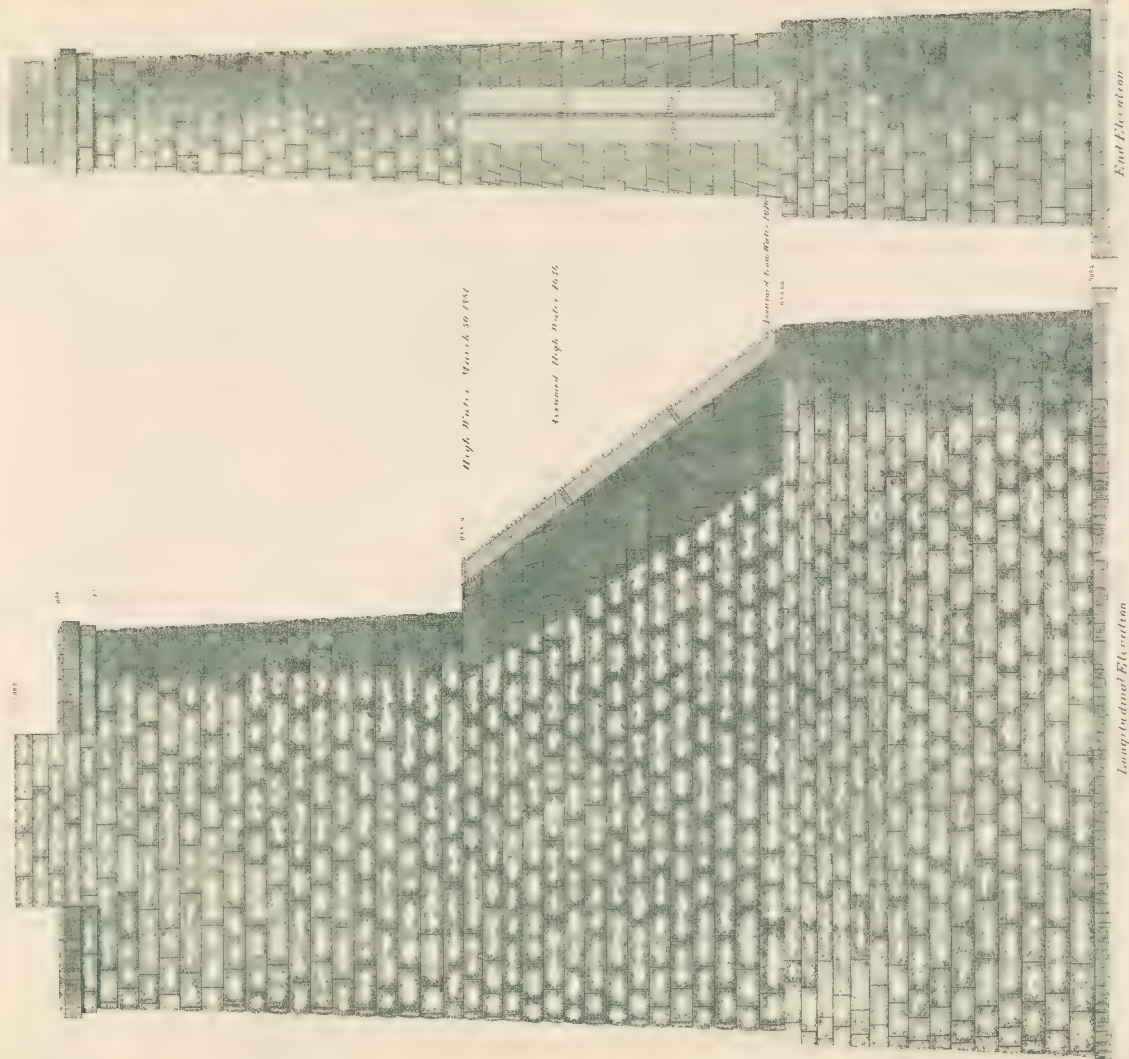
PIER No. 1

SCALE



Wm. S. Brown
Eng. & Archt.

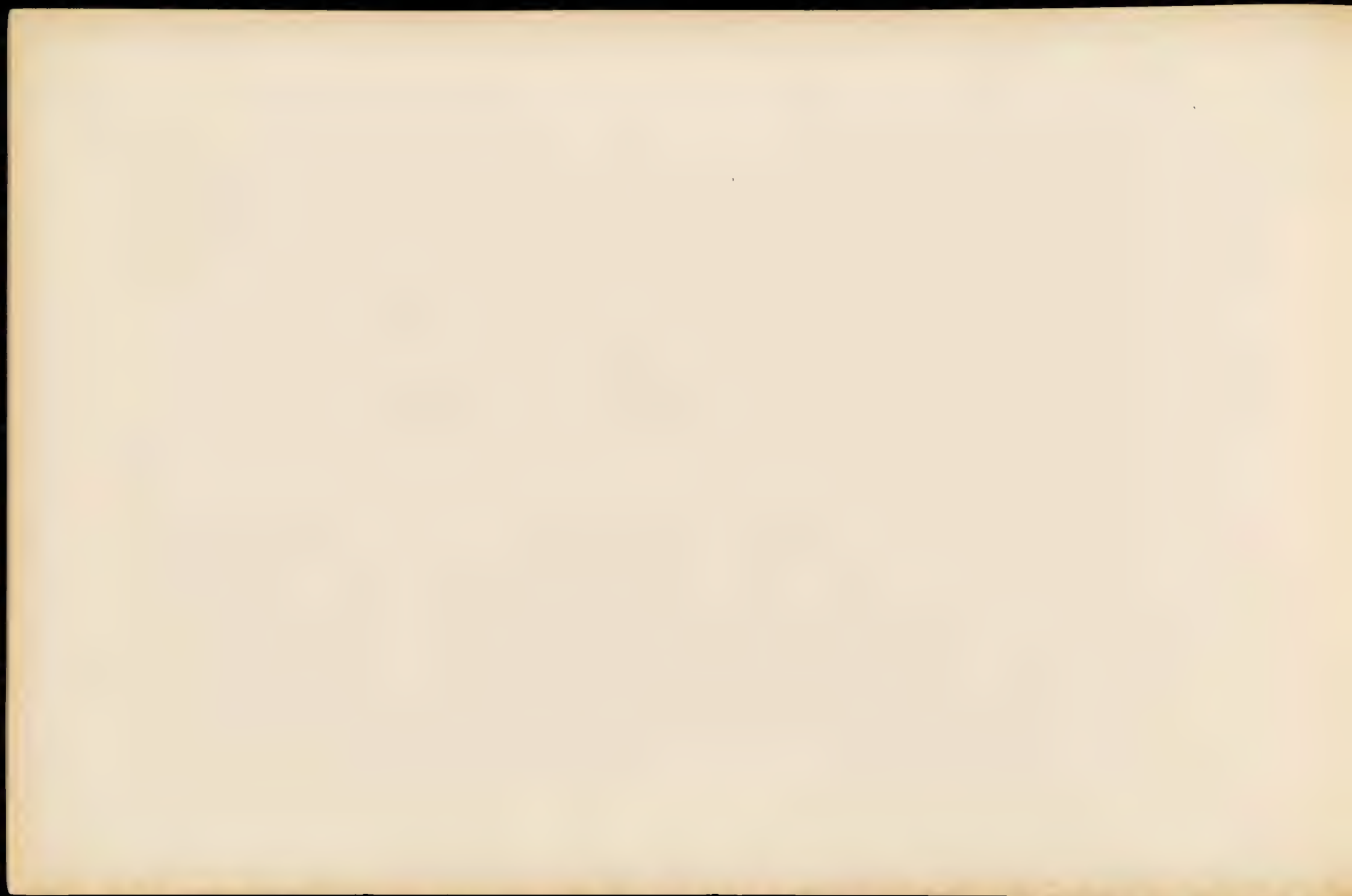




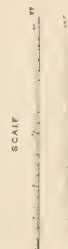
NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
MASONRY OF PIER II

SCALE
1" = 10'

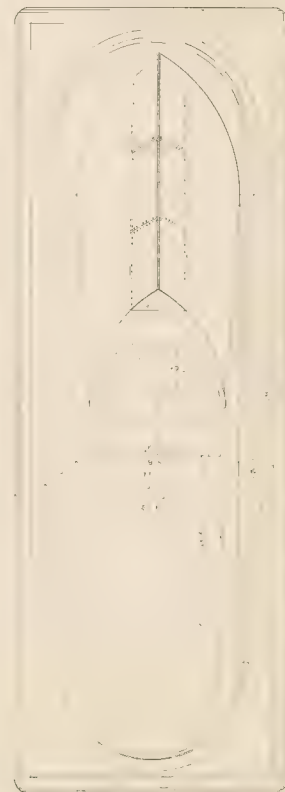
2 1/2' 0" 1/2'



NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
MASONRY OF PIER III

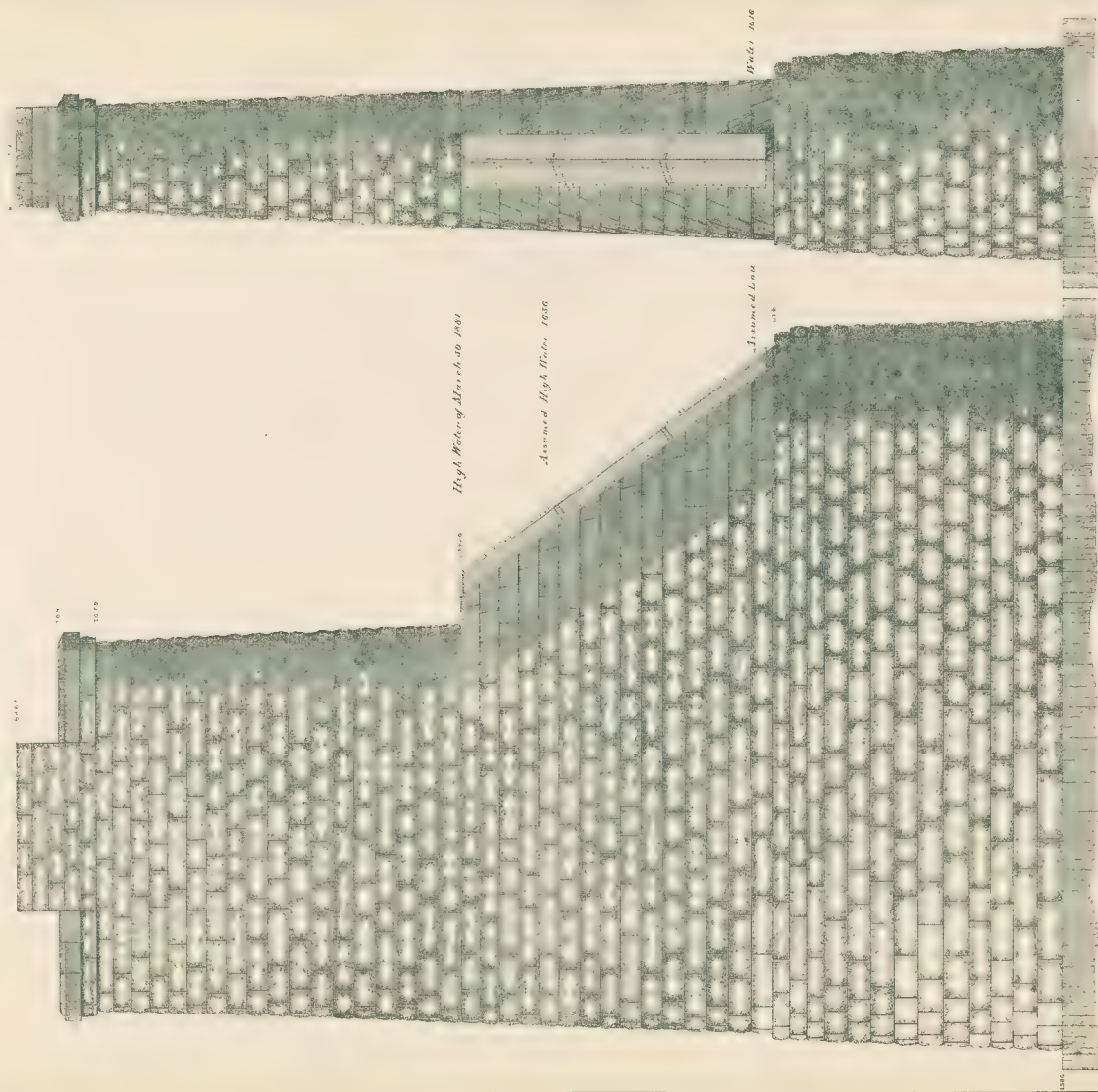


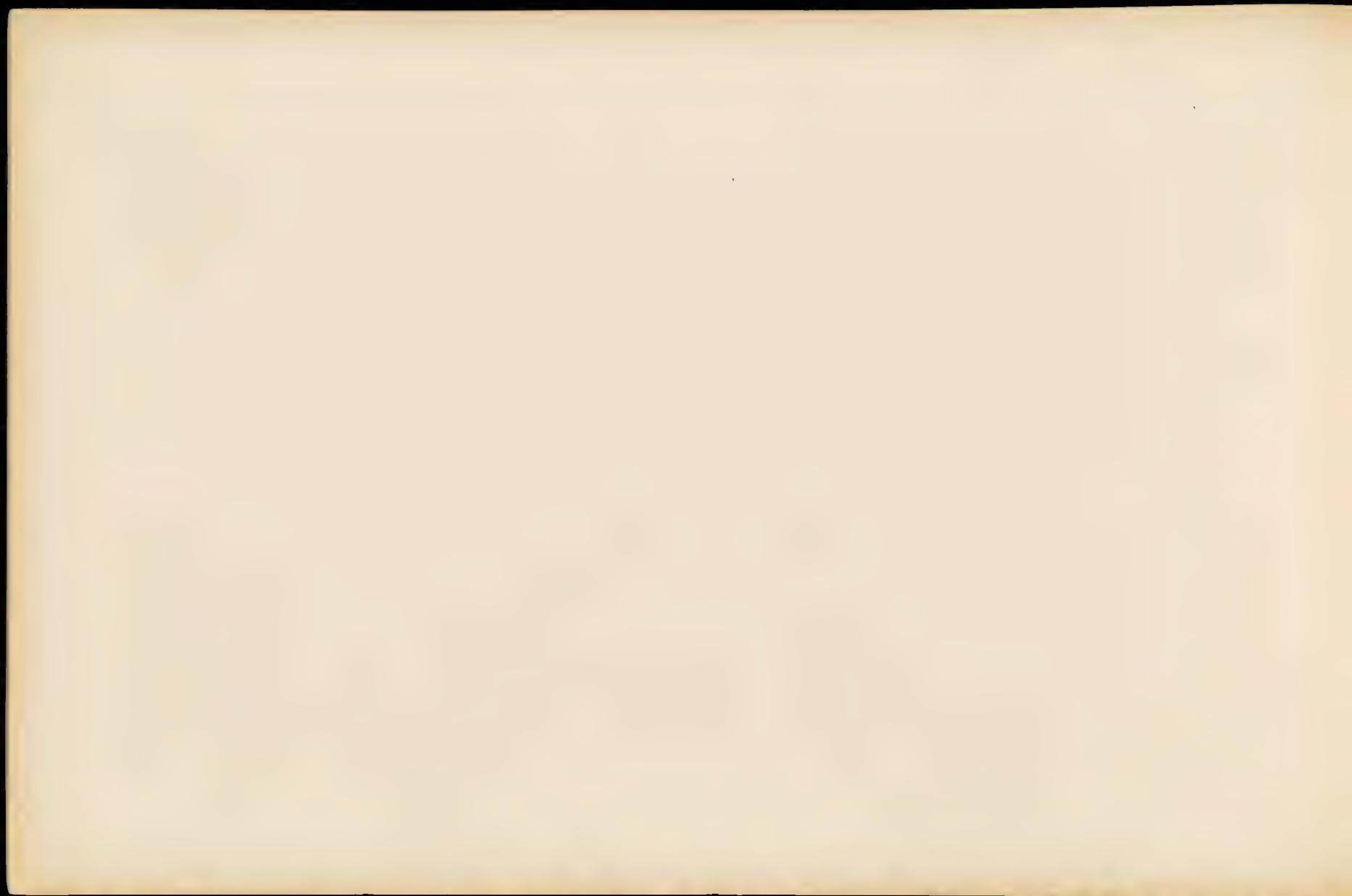
L. S. Moore
Eng. & Archt.



Front Elevation

Longitudinal Elevation



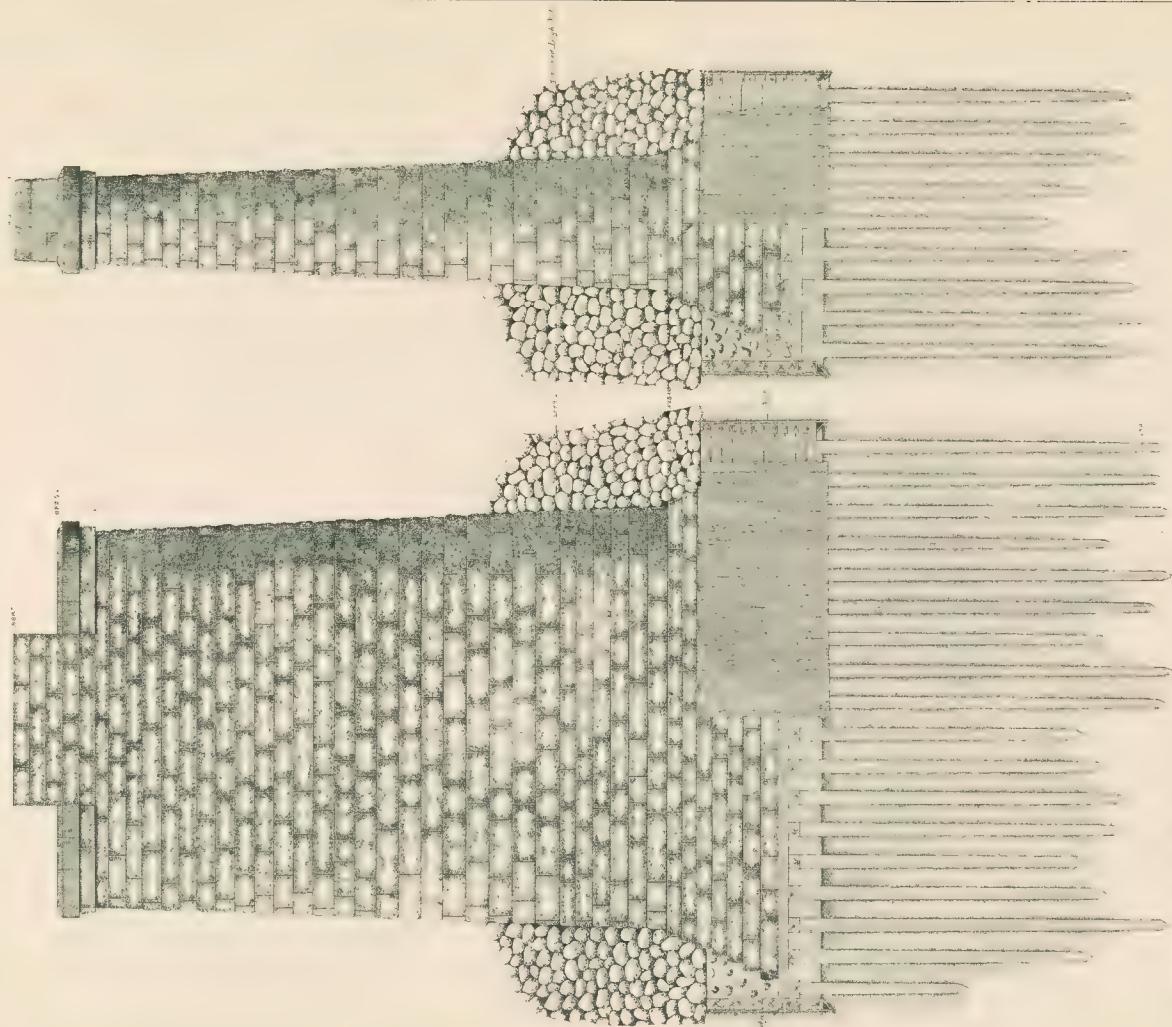


NORTH PACIFIC COAST
BISMARCK BRIDGE

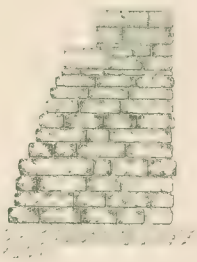
PIER IV

SCALE

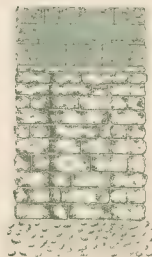
L. S. Brown
Sept 5, 1904





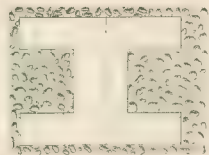


Longitudinal Elevation.



End Elevation.

NORTHERN PACIFIC RAIL ROAD.
BISMARCK BRIDGE.
 East Abutment and Foundation for Trestle Bent.



Plan

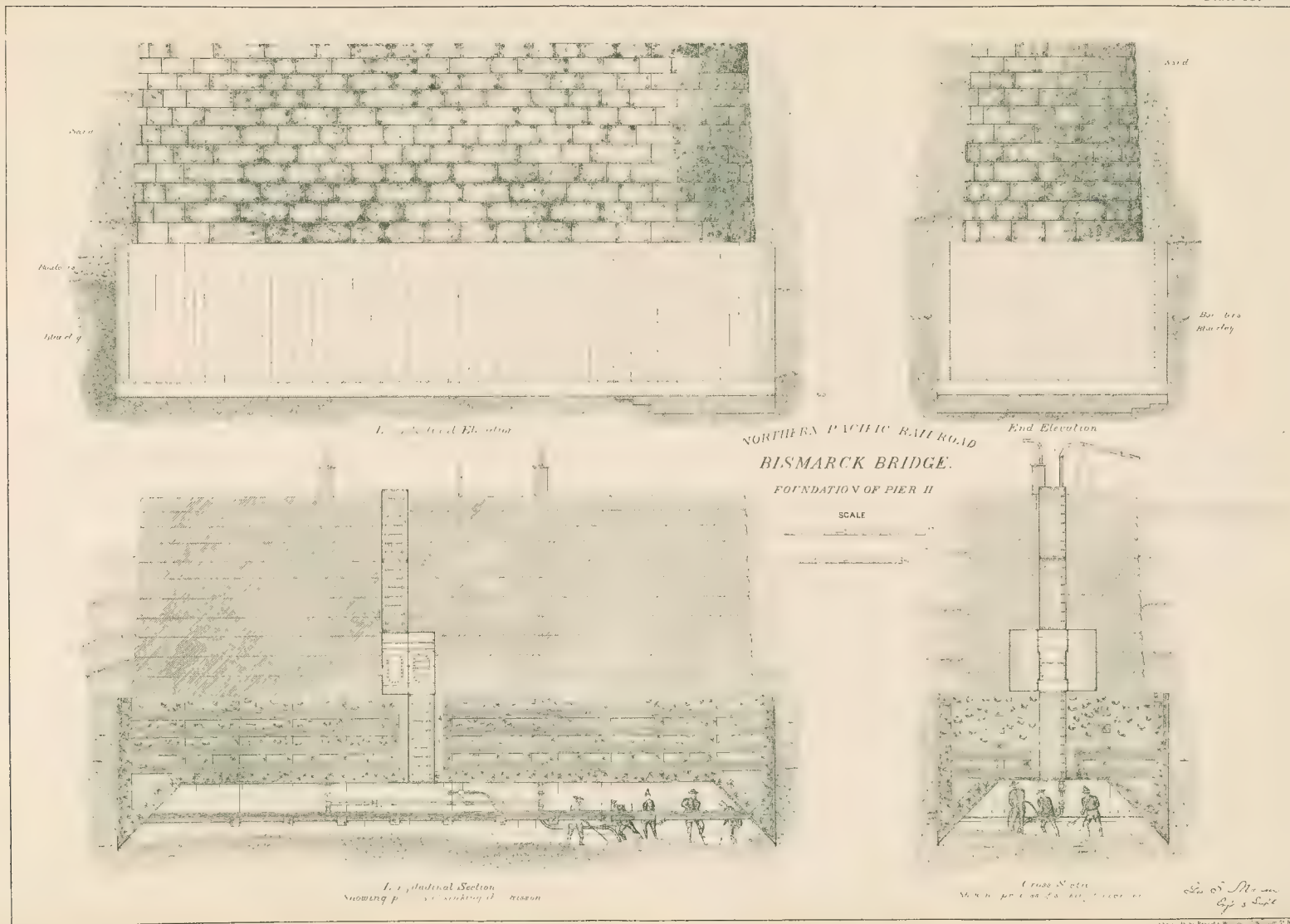
EAST ABUTMENT.



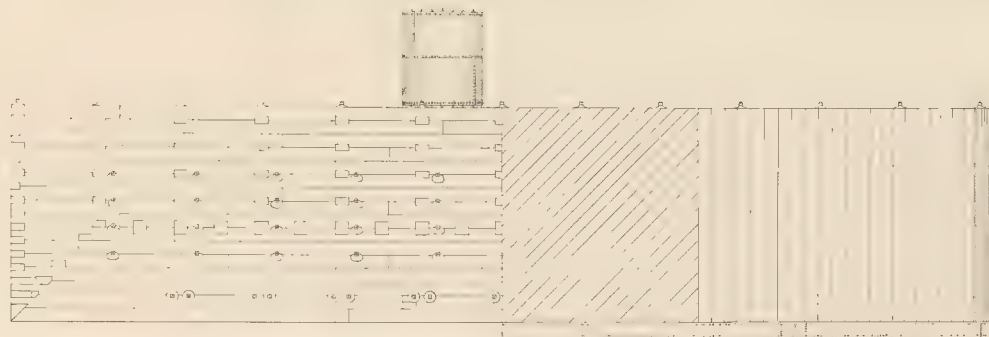
FOUNDATION for TRESTLE BENT.

S. S. Monro
 Supt. S. P. R.

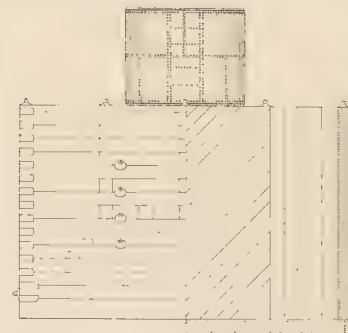




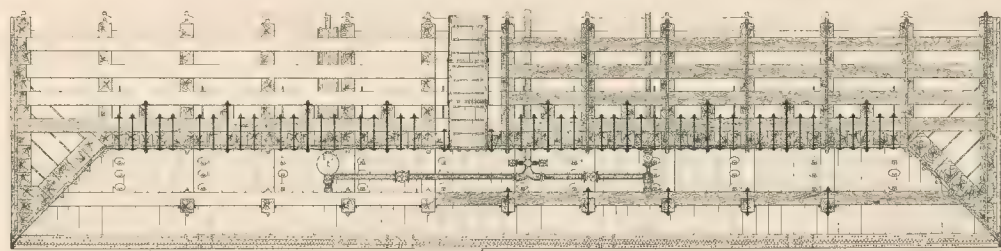




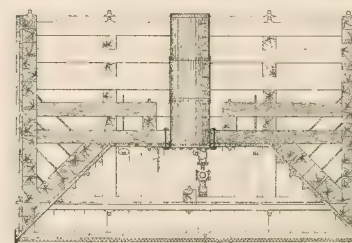
Longitudinal Elevation



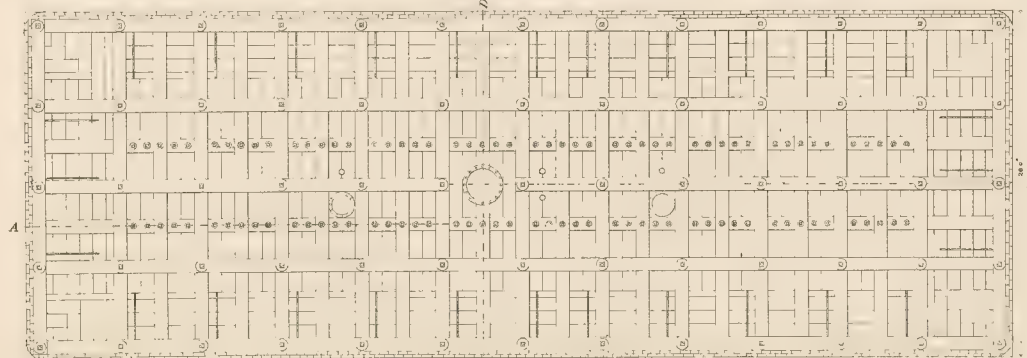
End Elevation



Section on A-B



Section on C-D.



Plan

NORTHERN PACIFIC RAILROAD

BISMARCK BRIDGE

CAISSON FOR PIER II.

SCALE.



L. S. Mosson
Eng. & Archt.

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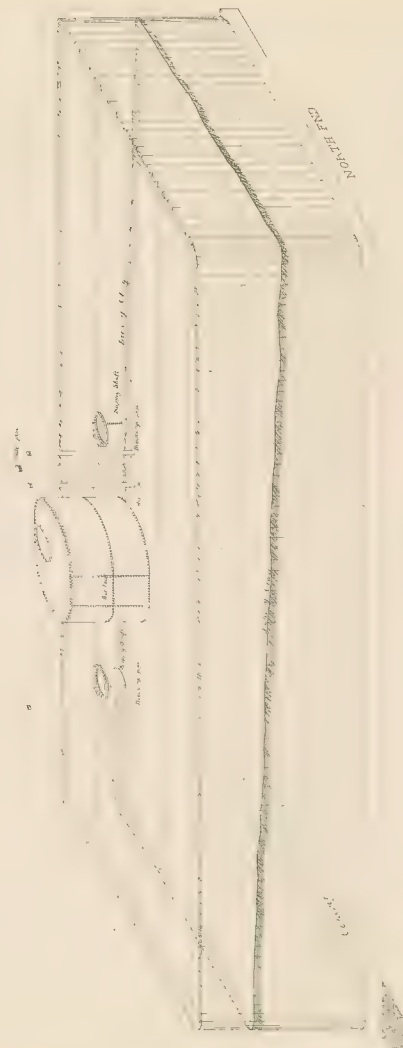
NORTHERN PACIFIC RAILROAD.

HISALAHEN BRIDGE.

SECTION OF LOWER PIER.
PLAN OF LOWER PIER.



PIER II



W. S. Morrison
1888



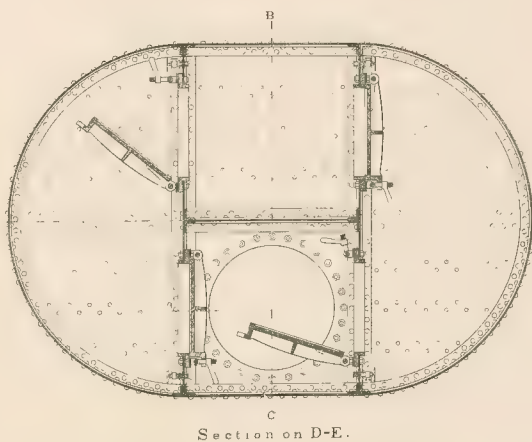
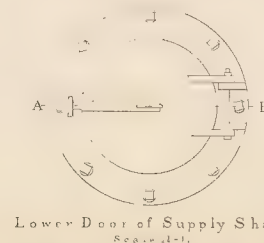
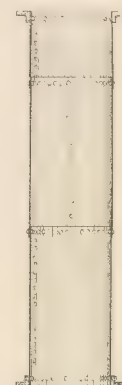
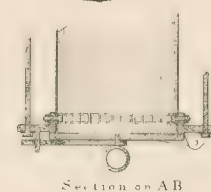
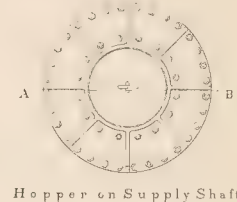
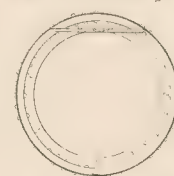
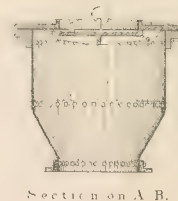
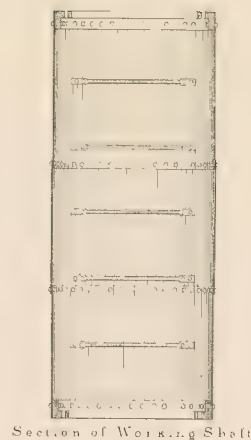
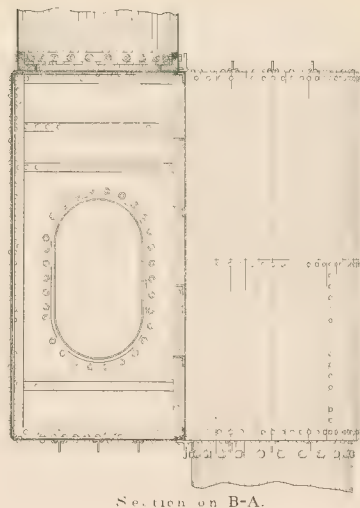
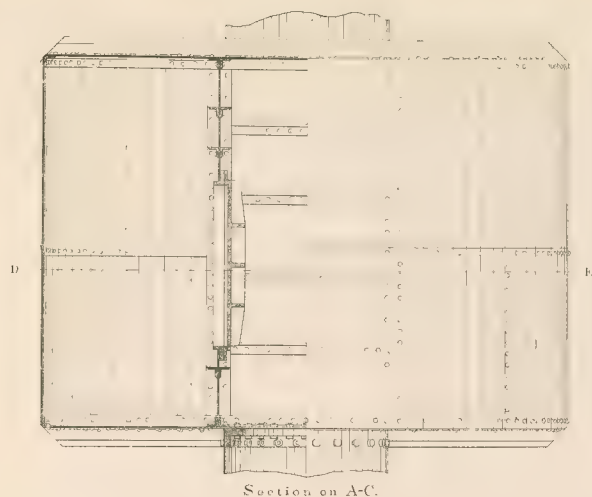
NORTHERN PACIFIC RAILROAD,
BISMARCK BRIDGE.

DIAGRAM SHOWING RATE OF PROGRESS IN SINKING CAISSONS.

*L. S. Munn
Eng'g & Supt.*





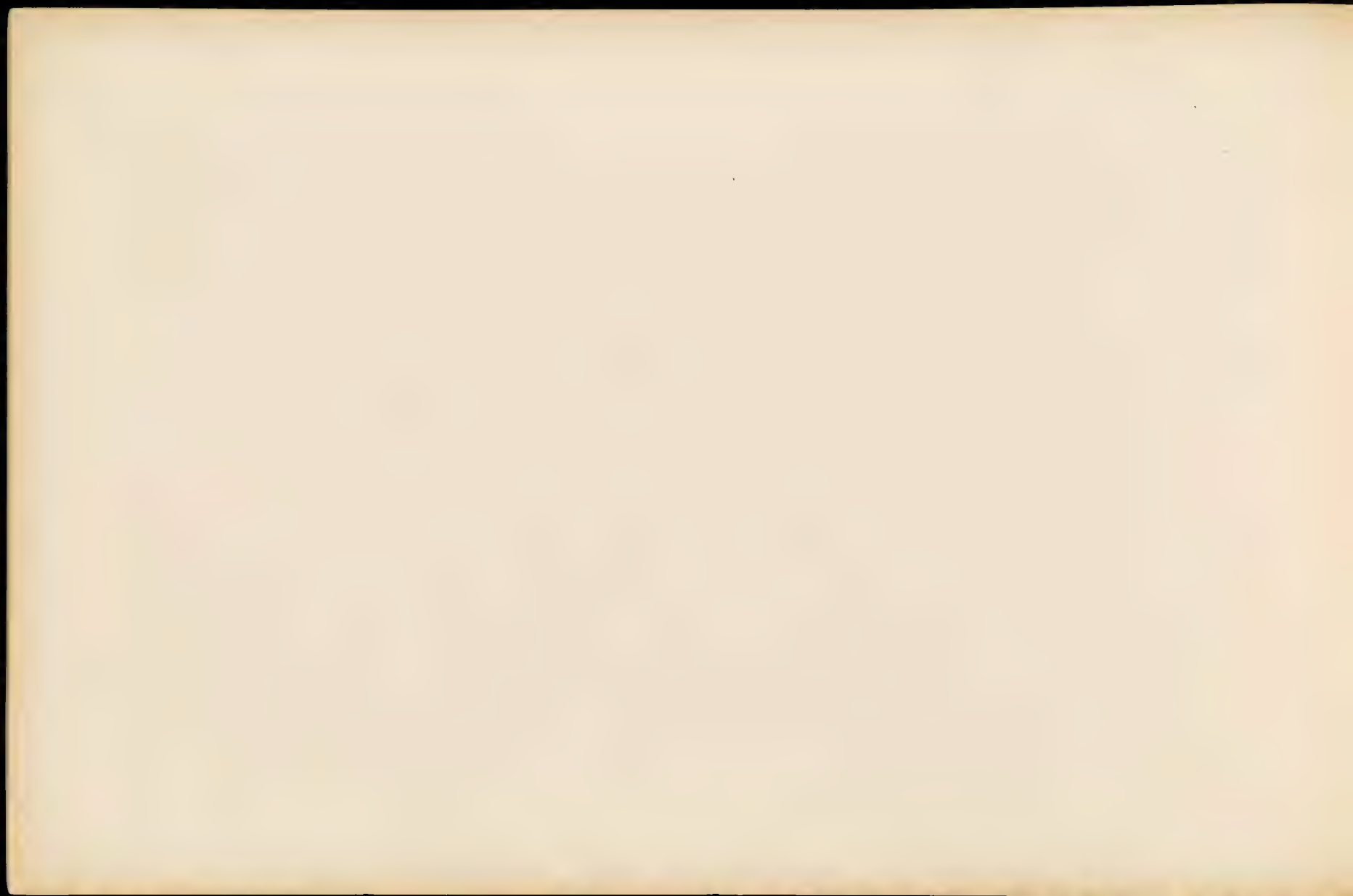


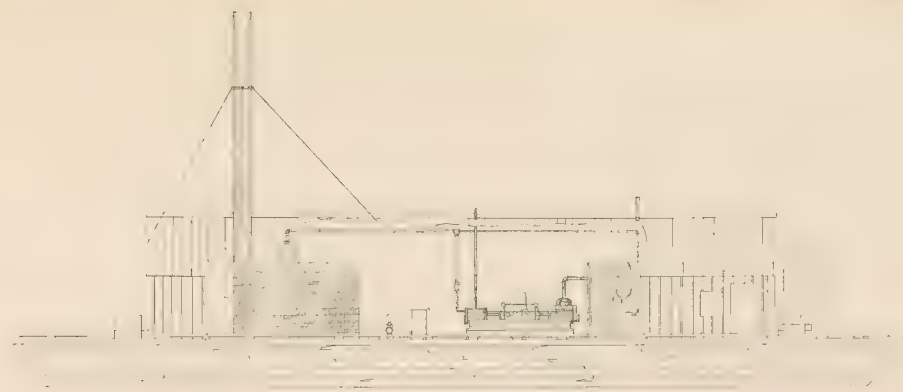
NORTHERN PACIFIC RAILROAD BISMARCK BRIDGE

AIR LOCK
AND OTHER DETAILS

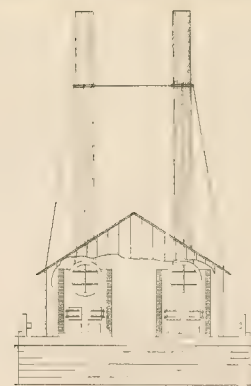


L. S. Morison
Chief Engineer

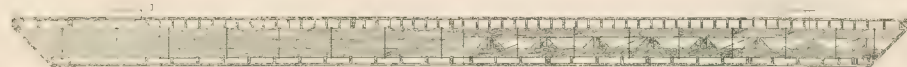




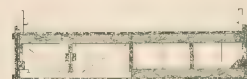
Longitudinal Elevation



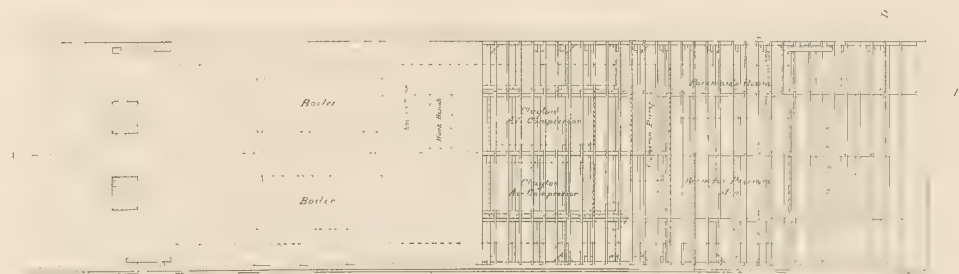
End Elevation



Section on A-B



Section on C-D

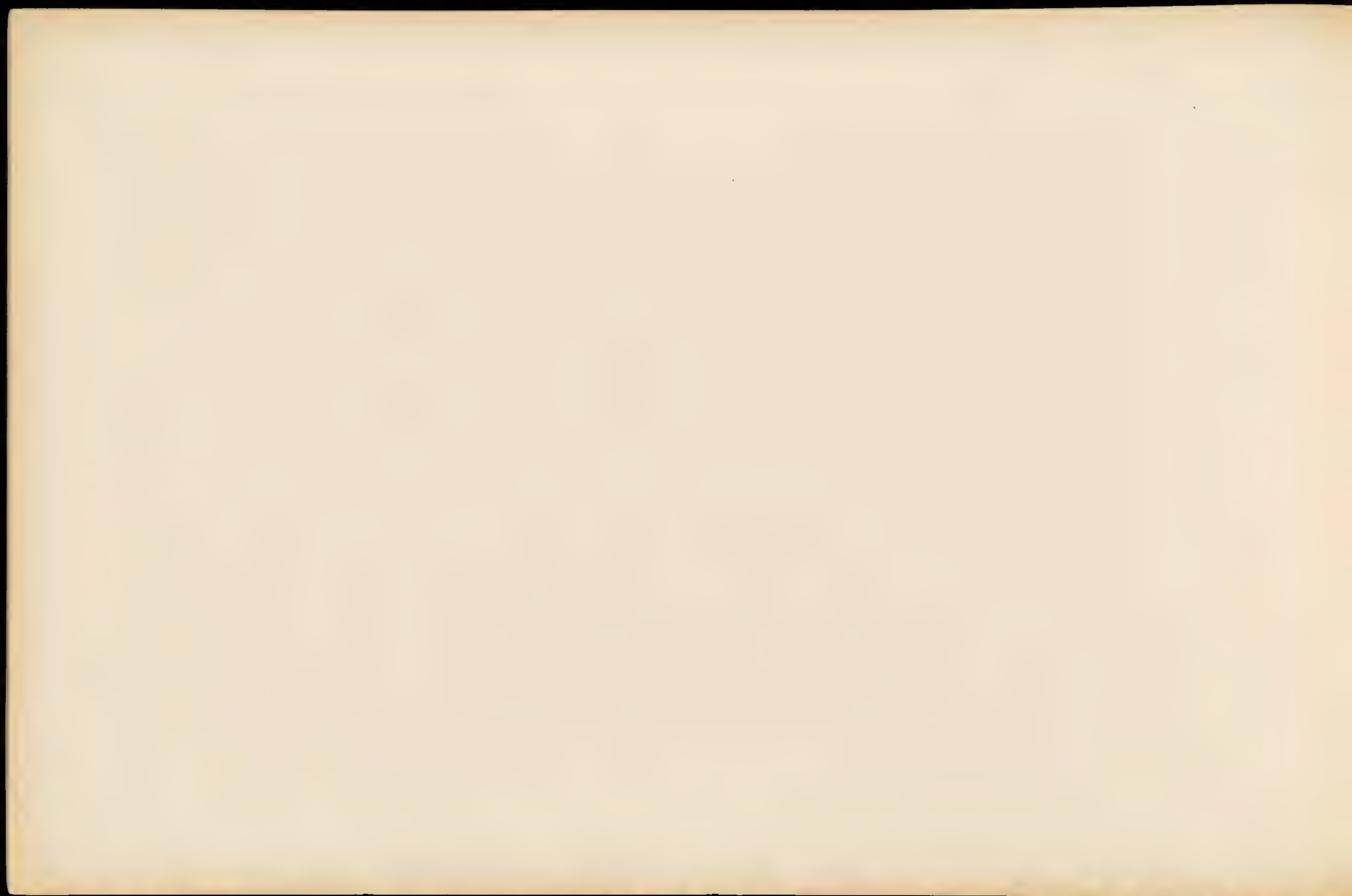


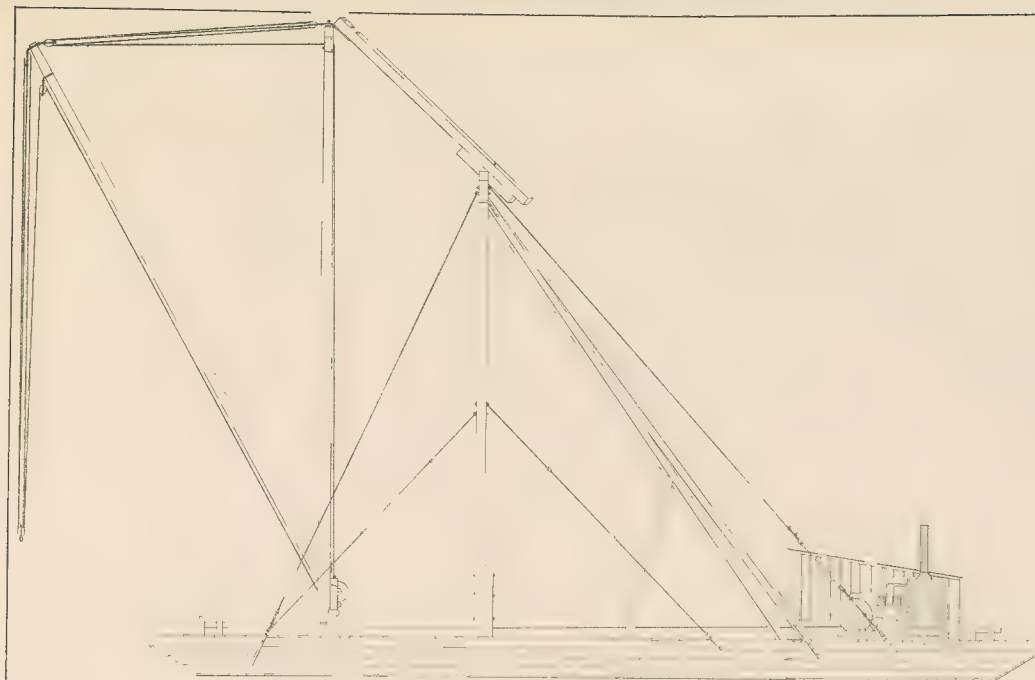
Plan

NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
MACHINERY BARGE

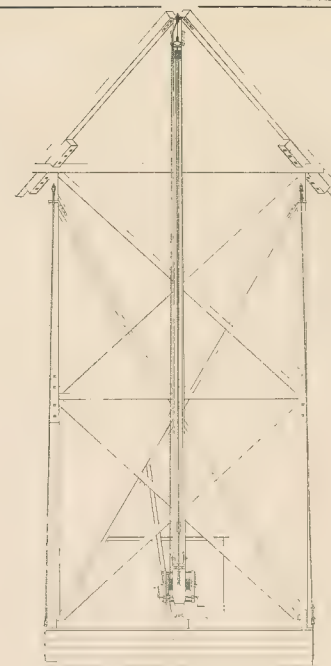
SCALE

J. S. Moore
Eng. 3-5-1

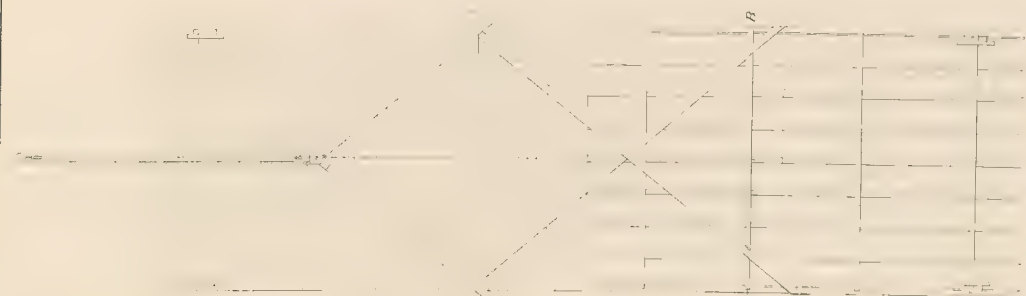




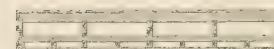
Longmen Elevation



End Elevation



Plan



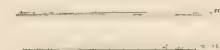
Section A-B

NORTHERN PACIFIC RAILROAD

BISMARCK BRIDGE

DERRICK BOOM

SCALE

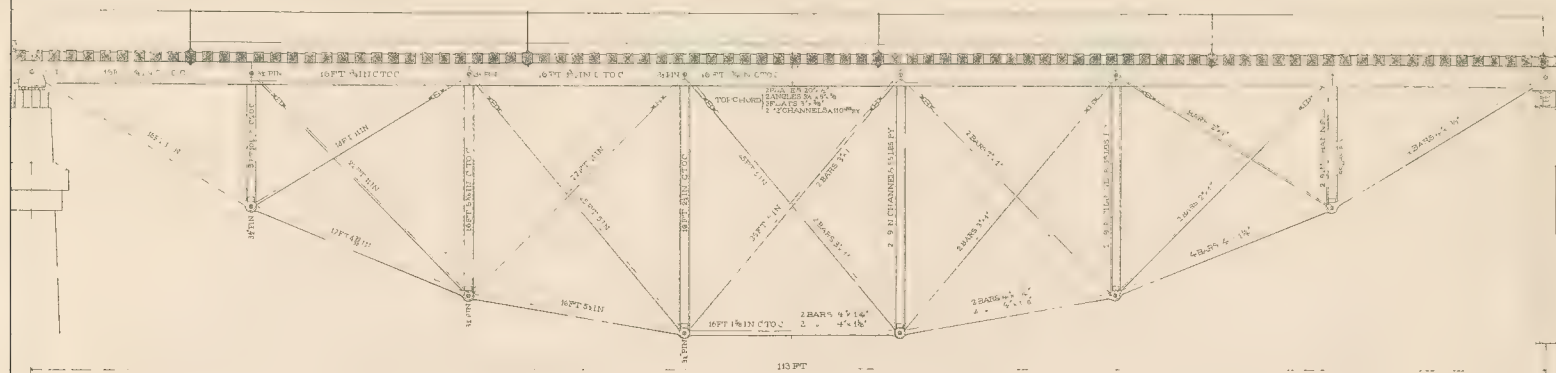


L. S. Moore
by J. L. Smith

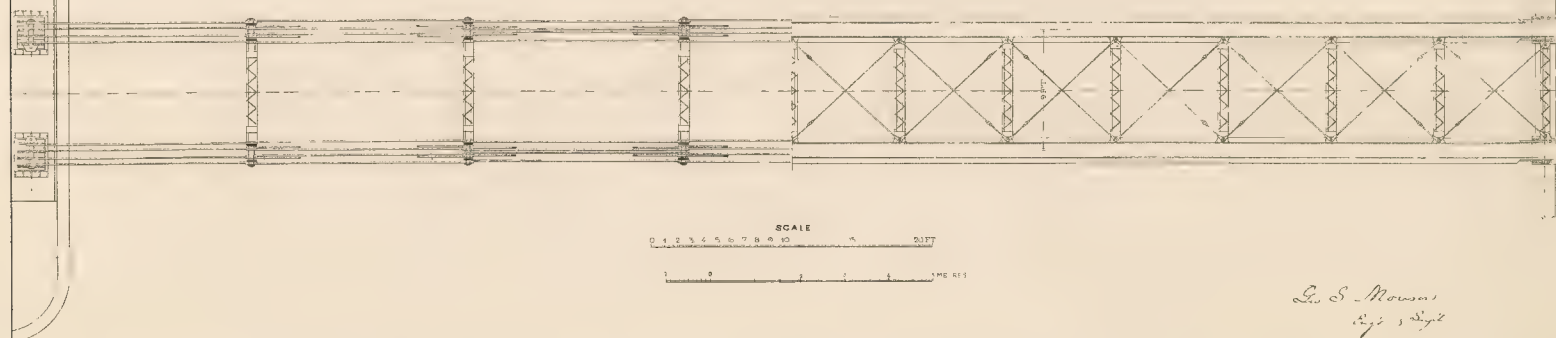


NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE.

ELEVATION OF 13 FT SPAN



FLAN
F
BOTTOM CHORD + TOP CHORD



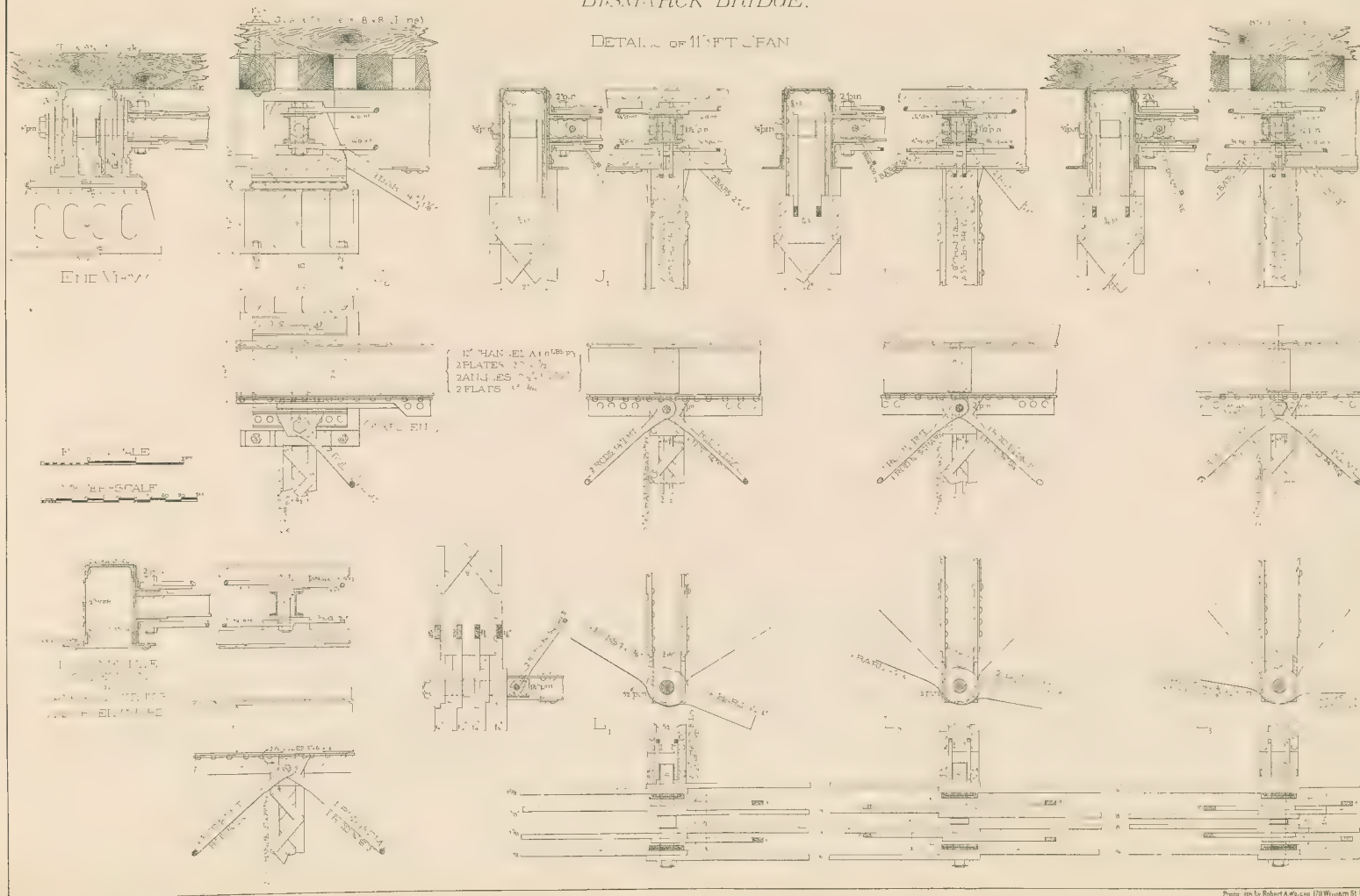
L. S. Mowser,
Esq., Esq.



NORTHERN PACIFIC RAIL ROAD
BISMARCK BRIDGE.

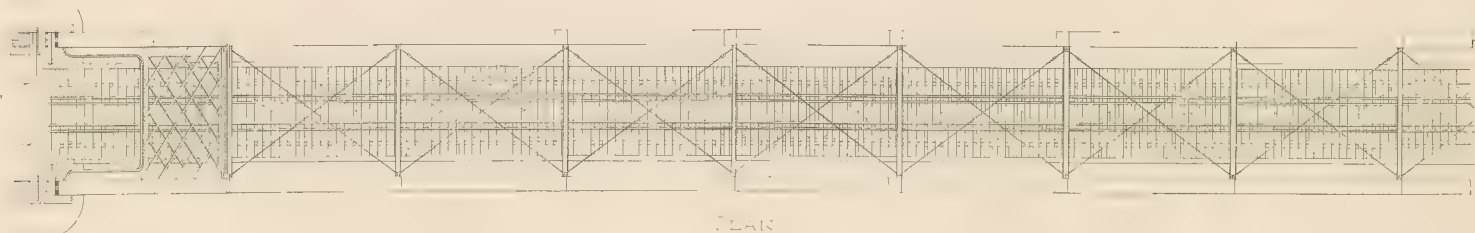
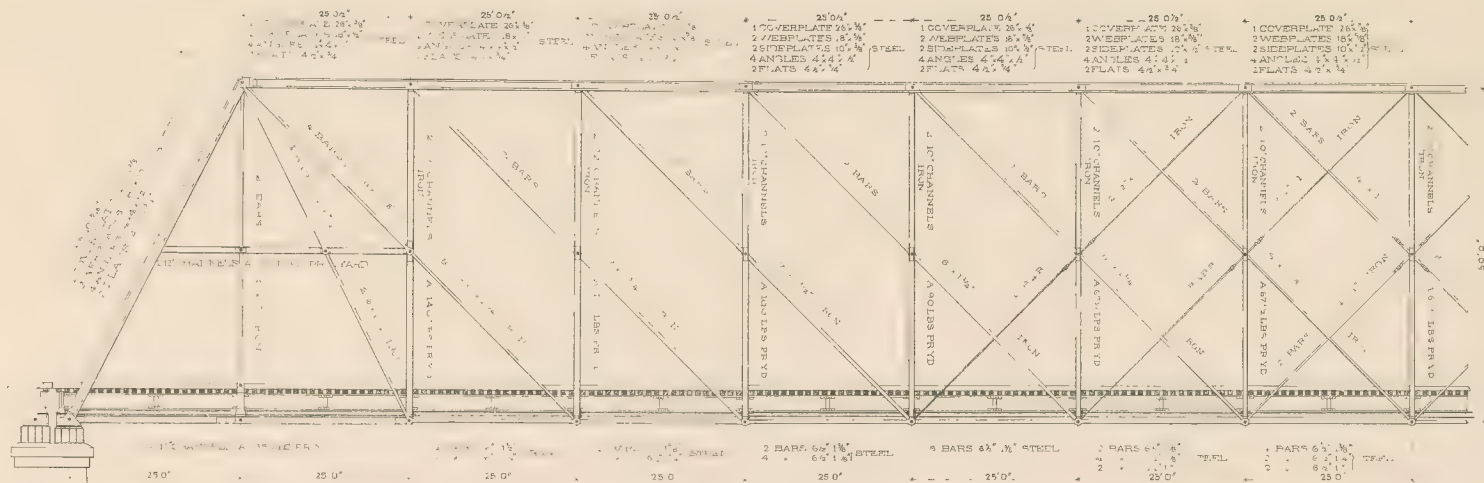
DETAIL OF 11 FT. SPAN

L. S. Moen
Supt. of Bridges



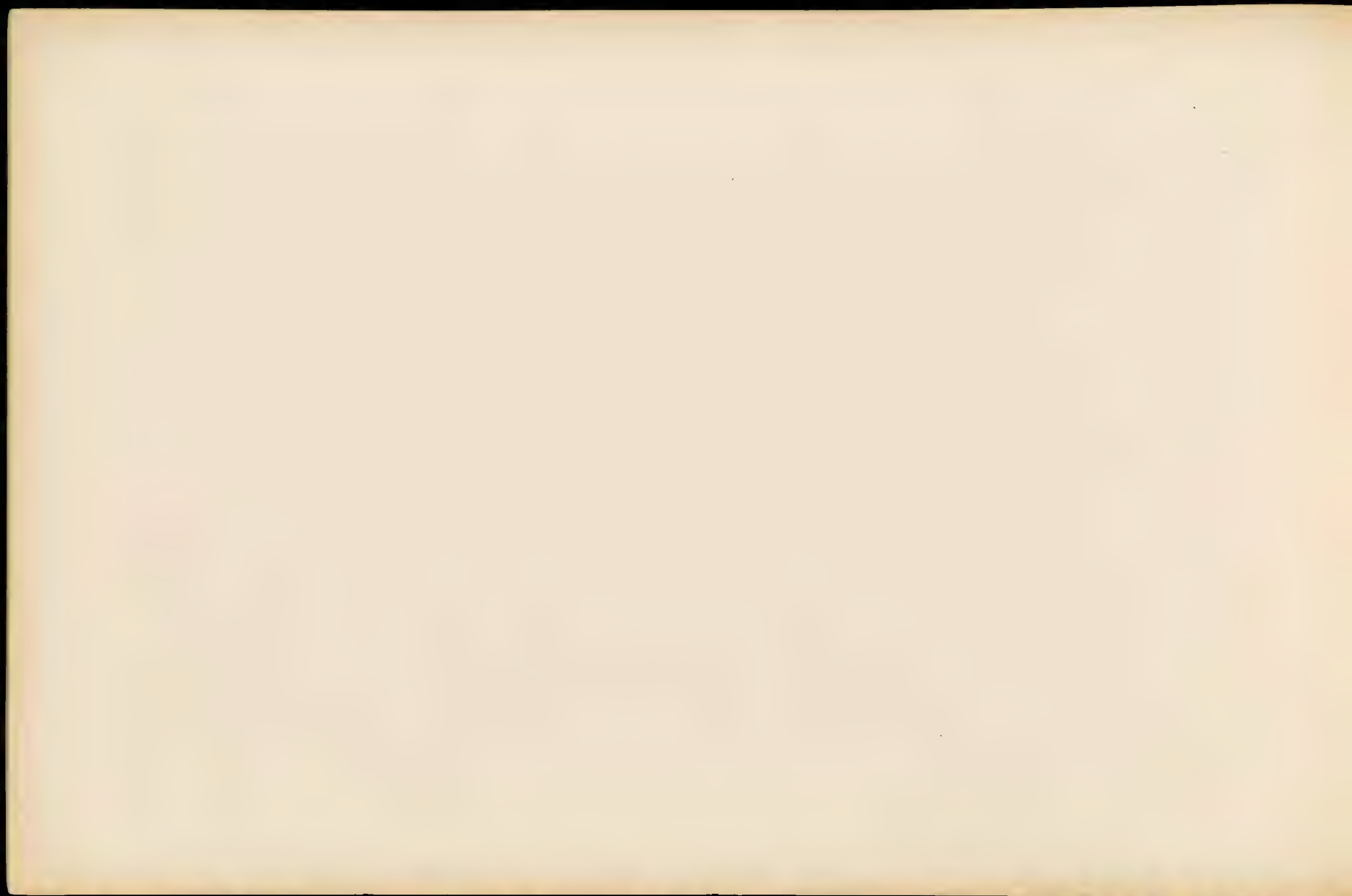


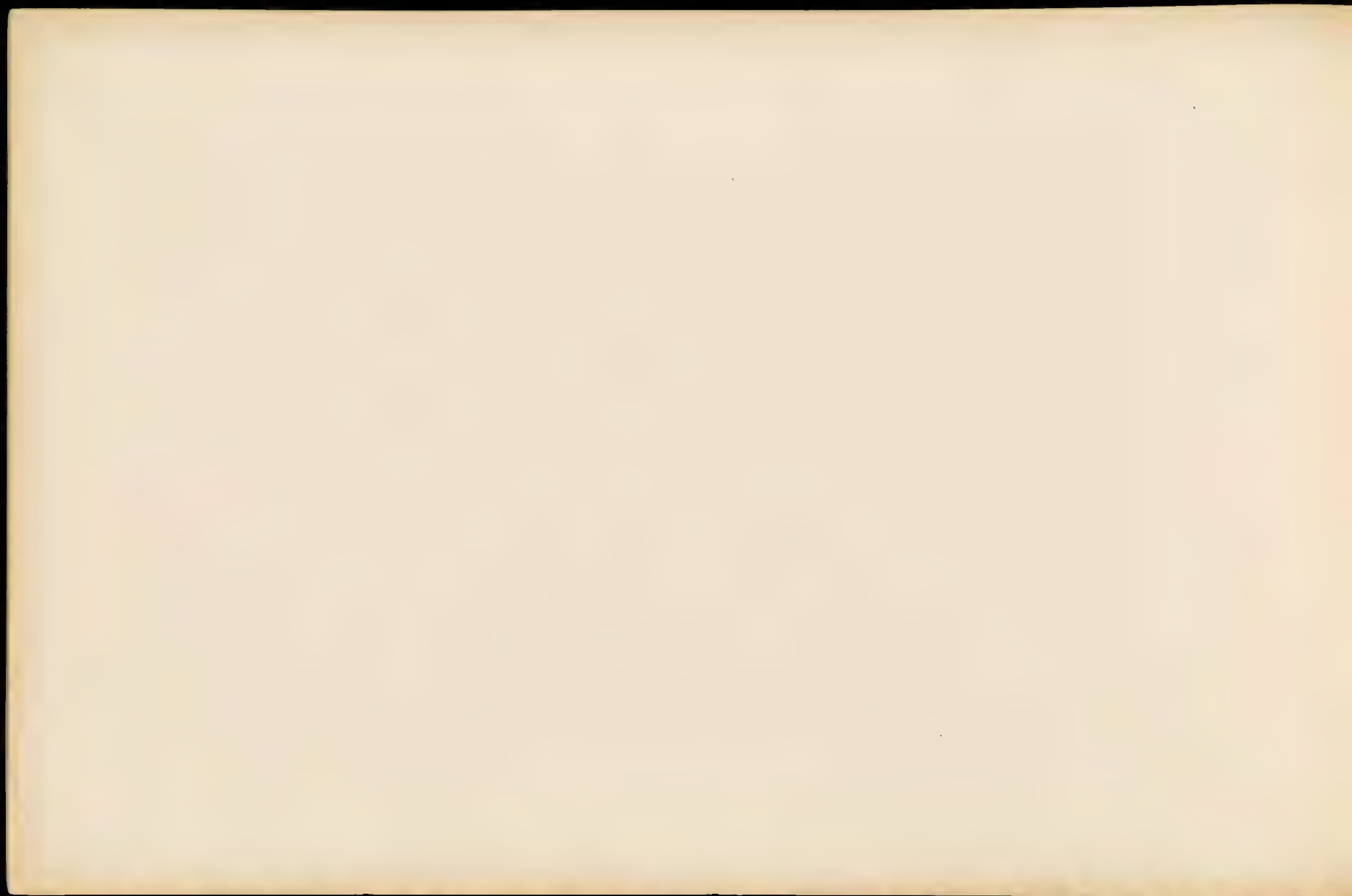
NORTHERN PACIFIC RAILROAD,
BISMARCK BRIDGE.
GENERAL ELEVATION & PLAN OF 400 FT SPAN.



SCALE

Lt. Col. Norman
Eng. & Sig.





NORTHERN PACIFIC RAILROAD

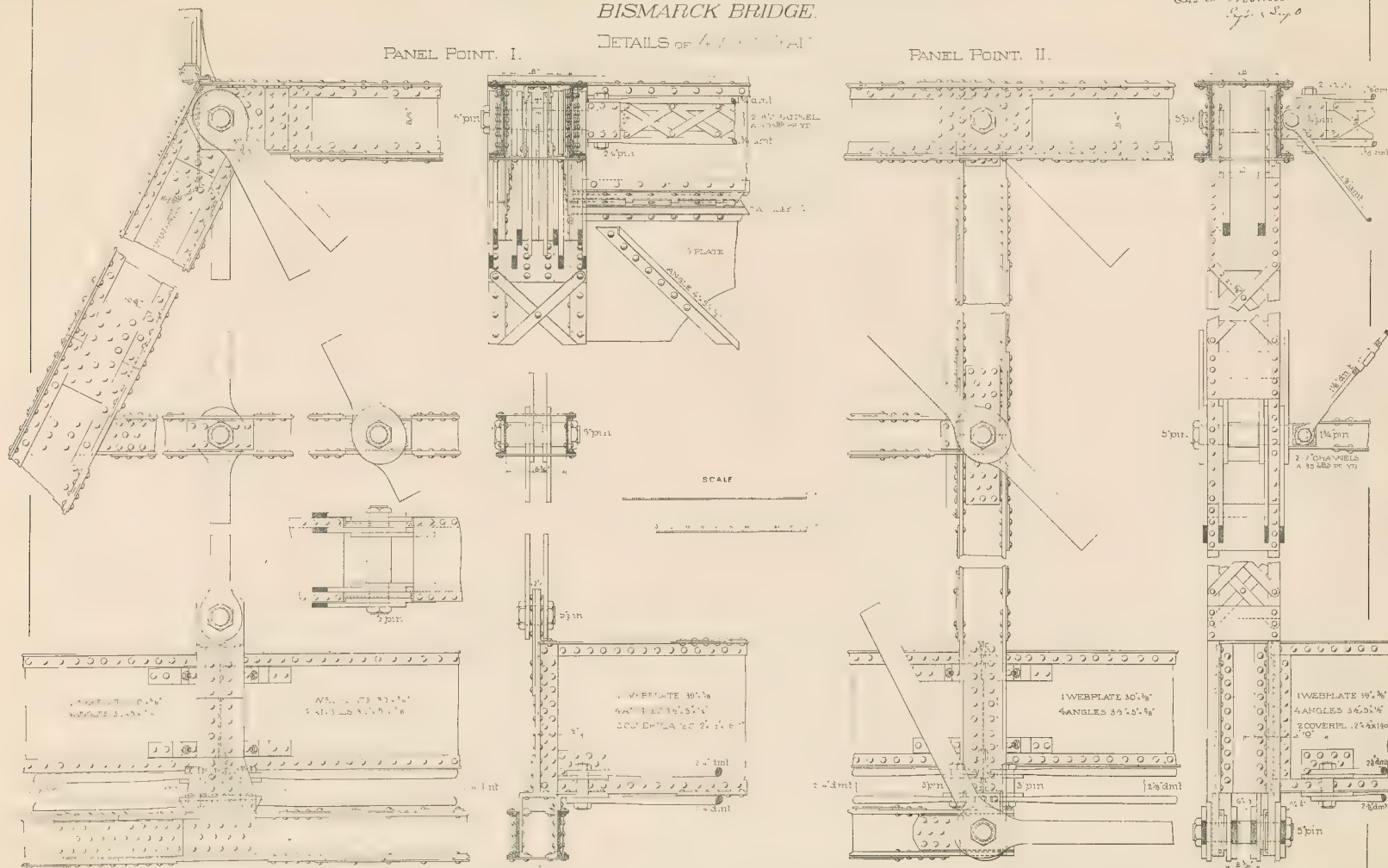
BISMARCK BRIDGE.

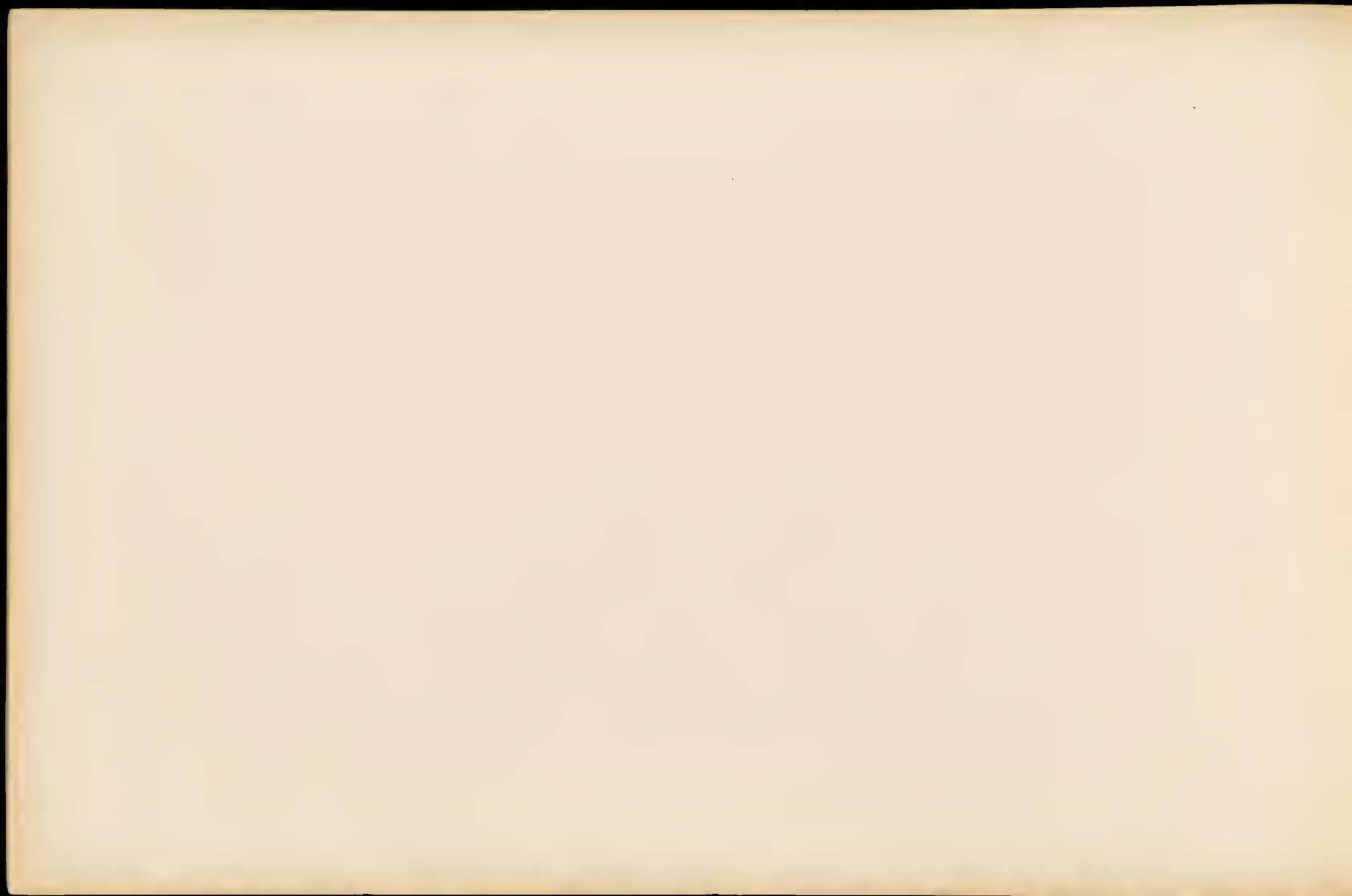
L. S. Morrison.
Eng. & Archt.

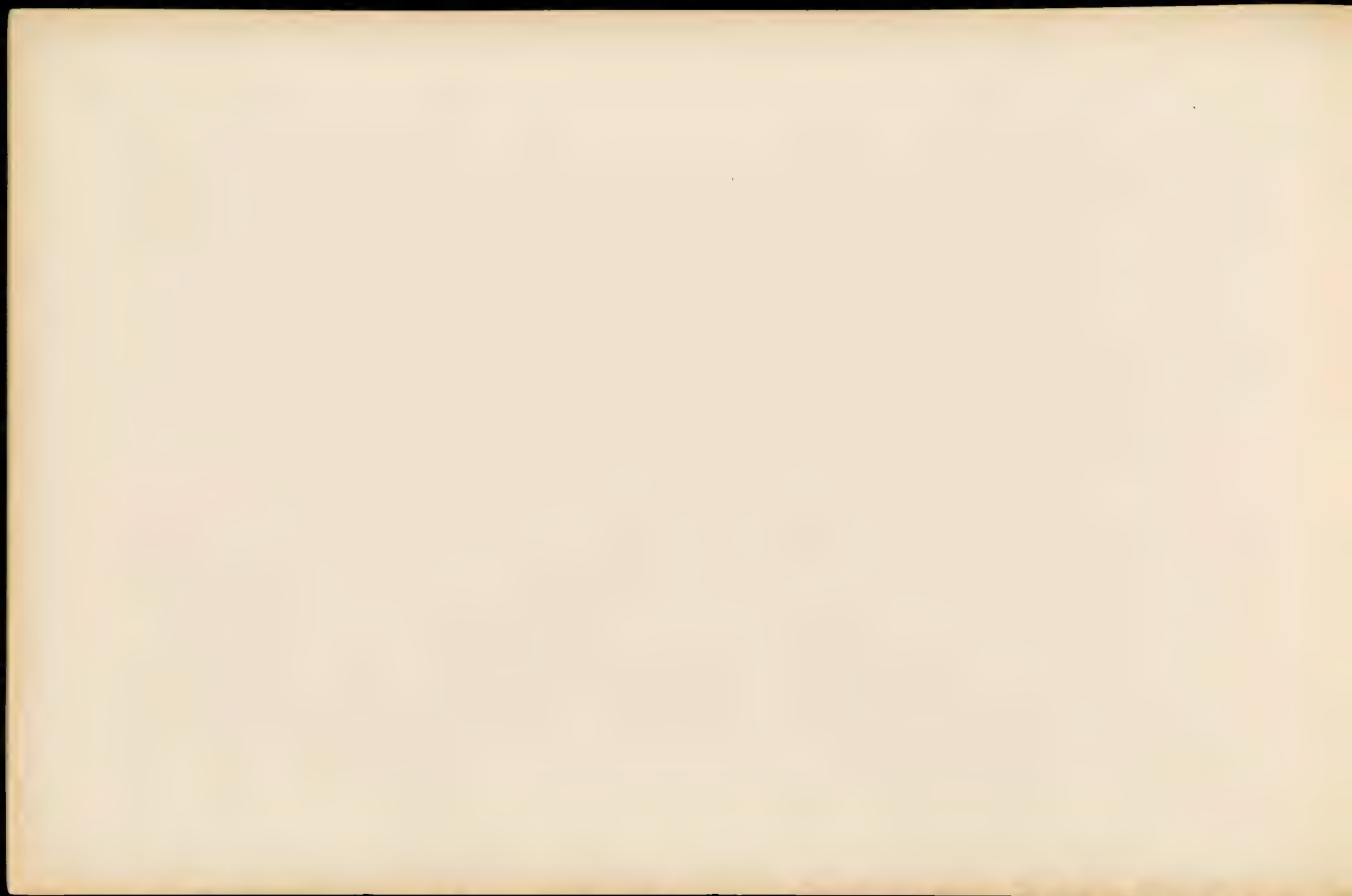
DETAILS OF PANEL POINT I.

PANEL POINT I.

PANEL POINT II.







NORTHERN PACIFIC RAILROAD

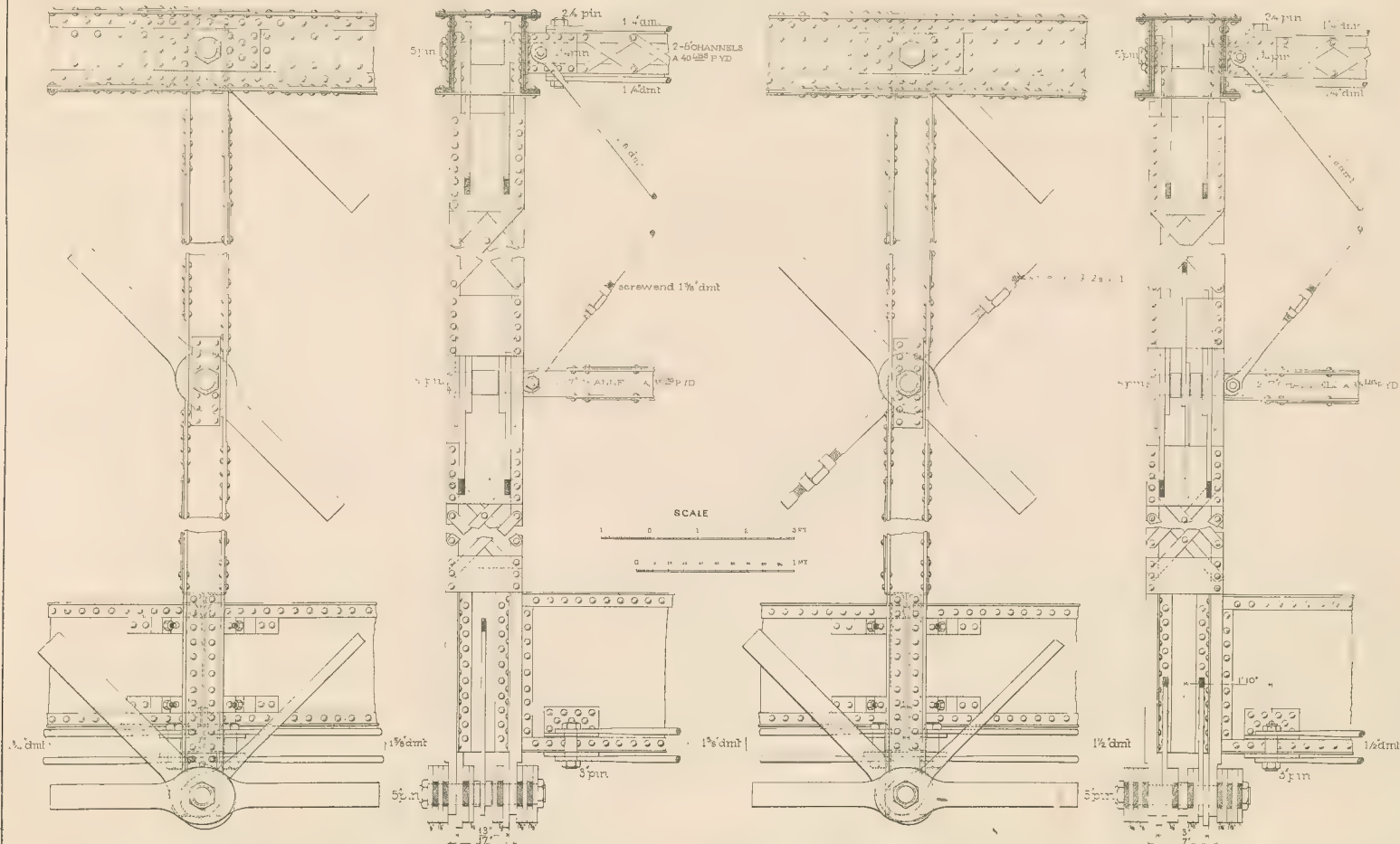
BISMARCK BRIDGE

DETAILS OF 400 FT SPAN

Geo S. Mowson
Esq. & Esq^{ts}

PANEL POINT V

FANEL POINT VI





NORTHERN PACIFIC RAILROAD

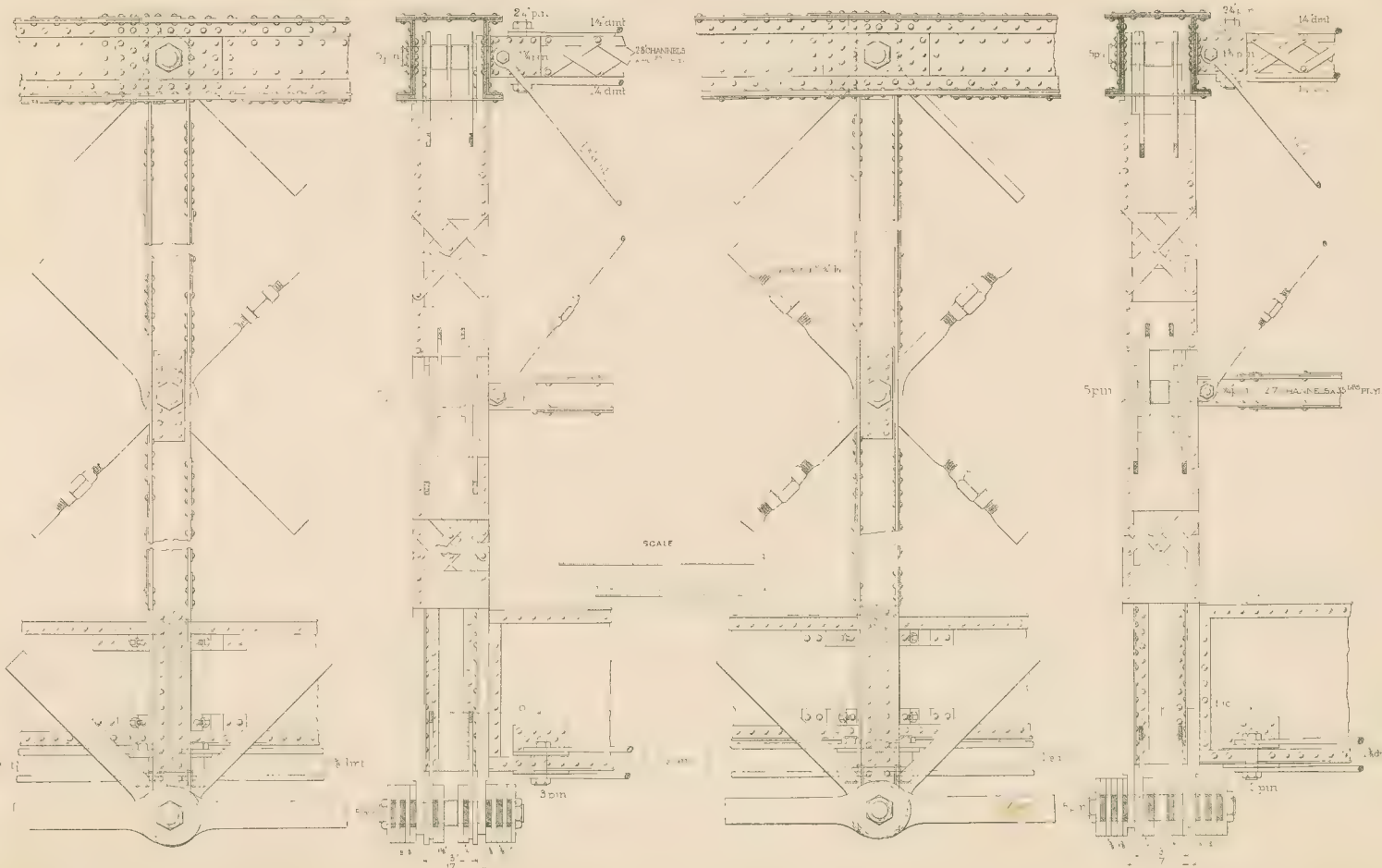
BISMARCK BRIDGE

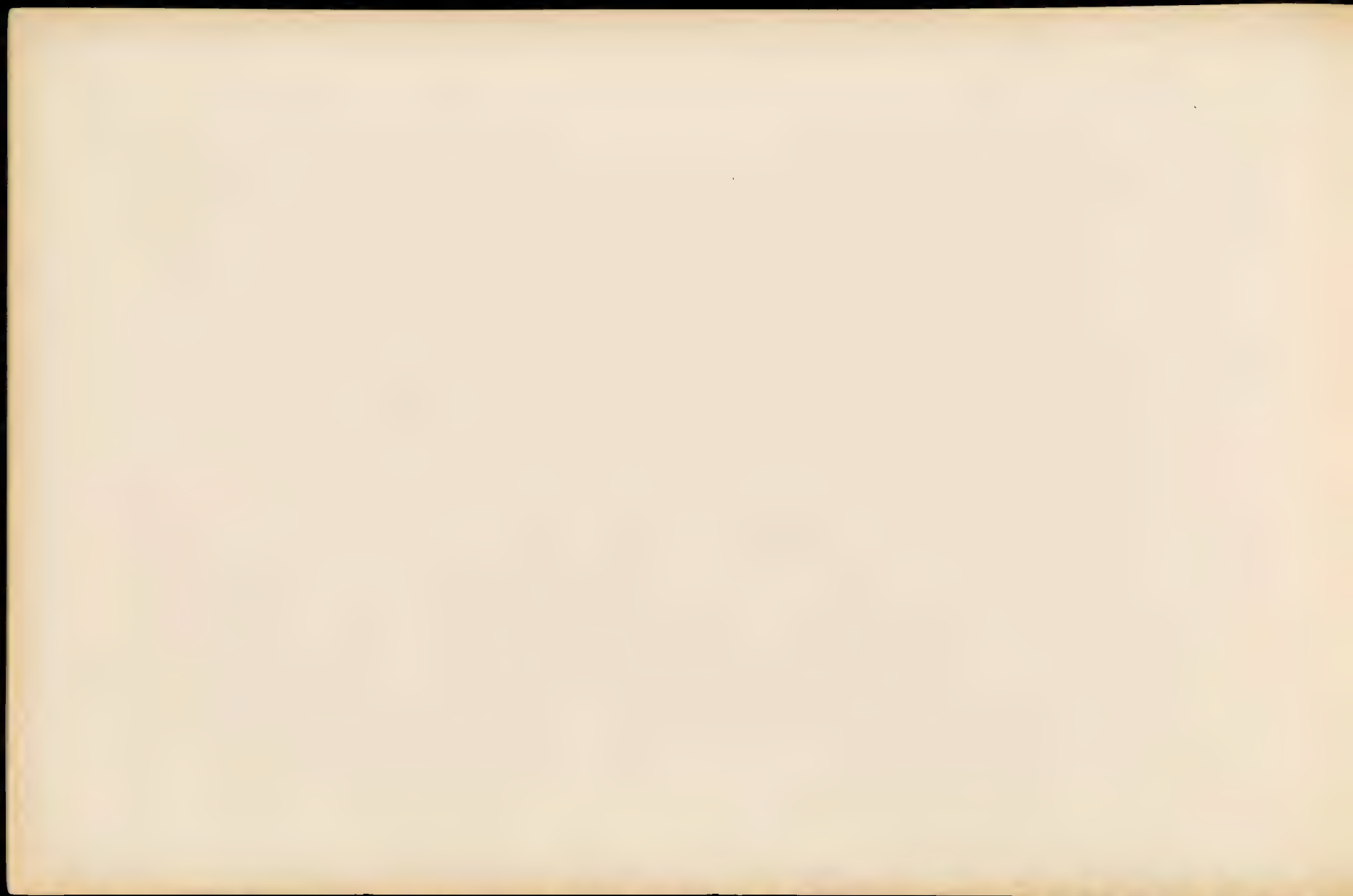
DETAILS OF 400 FT SPAN

L. S. MASON.
Eng'r & Supr

PANEL POINT VI.

PANEL POINT VII.

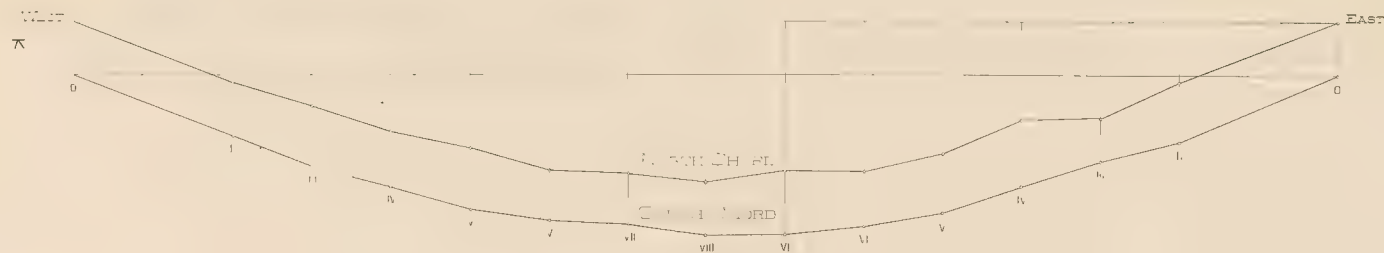




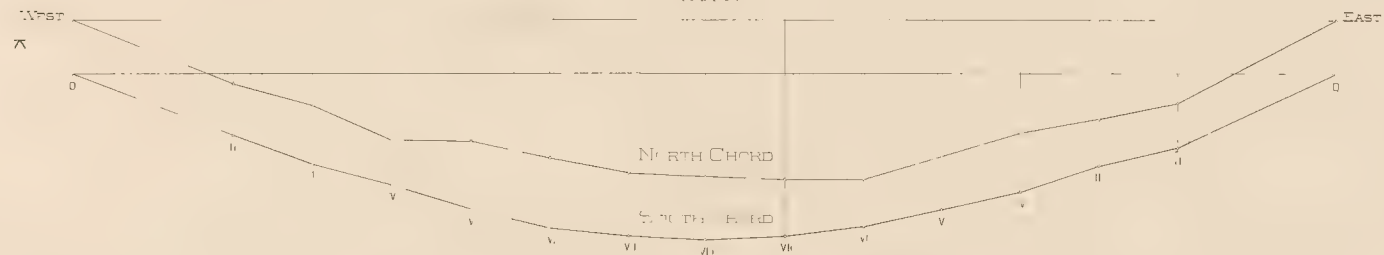
NORTHERN PACIFIC RAILROAD
BISMARCK BRIDGE
DEFLECTION OF TRUSSES
UNDER TEST-LOAD OF 8 MOGUL LOCOMOTIVES

Geo. S. Morison
Eng. & Archt.

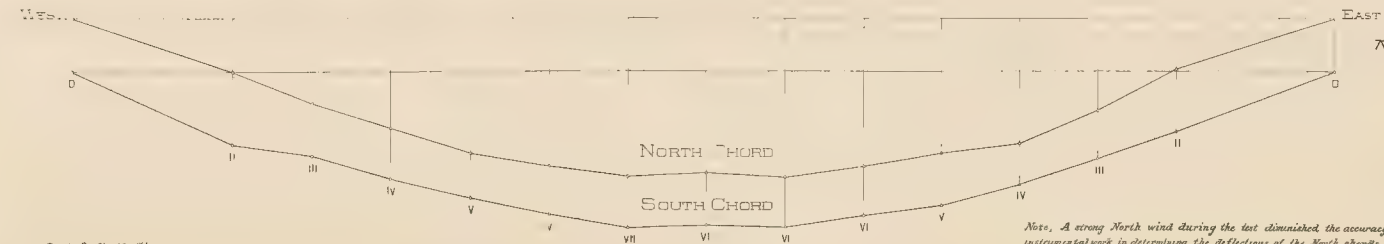
SPAN A



SPAN B

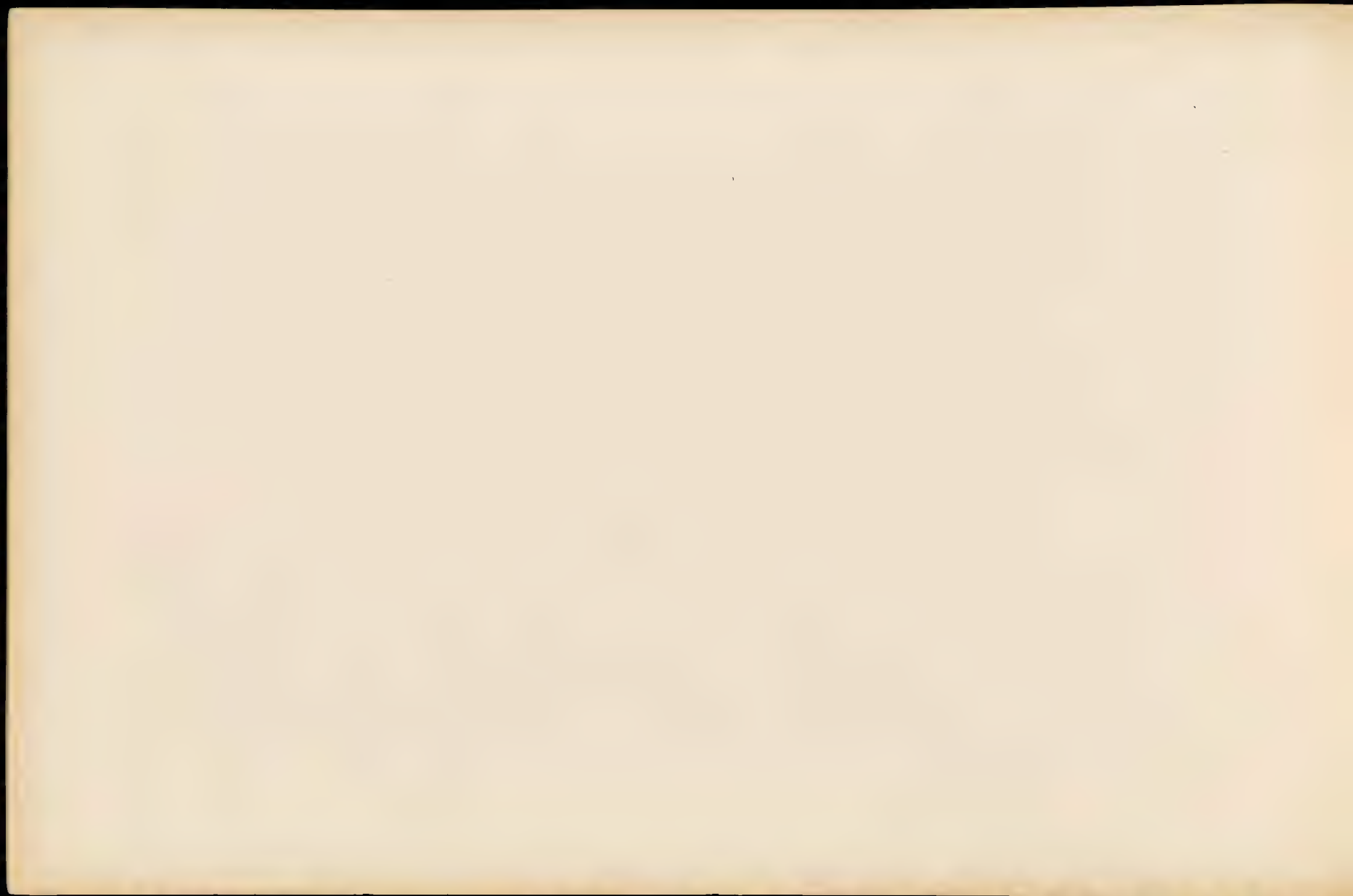


SPAN C



Vertical Scale $\frac{3}{8}$ Full Size

Note, A strong North wind during the test diminished the accuracy of the instrumental work in determining the deflections of the North chords



NORTHERN PACIFIC RAILROAD

BISMARCK BRIDGE

ASSUMED LIVE LOAD - 400 FT SPAN

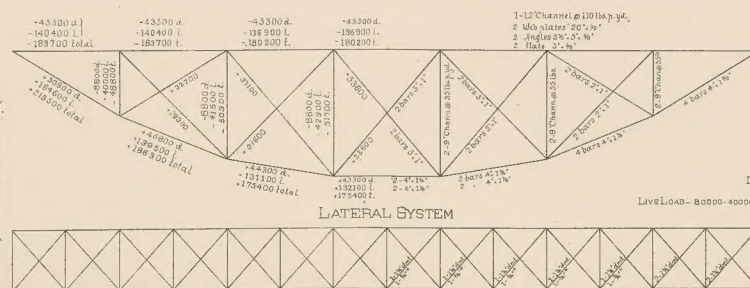
100000-50000-100000-50000-50000 ETC: ON SUCCESSIVE PANEL POINTS

STRAIN SHEETS

UPPER LATERAL SYSTEM



LOWER LATERAL SYSTEM



ASSUMED LOADS - 113 FT SPAN

DEAD LOAD - 8600^{lbs} PER PANEL PER TRUSS

LIVELOAD- 80000-40000-40000-80000-40000-40000 ETC. ON SUCCESSIVE PANEL POINTS

Geo. S. Morrison.
Eng'r & Supt

91-B12500

